US008004814B2

(12) **United States Patent**
Maraval et al.

(10) **Patent No.:** **US 8,004,814 B2**
(45) **Date of Patent:** ***Aug. 23, 2011**

(54) **METHOD AND APPARATUS FOR CONTROLLING A LIFTING MAGNET SUPPLIED WITH AN AC SOURCE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 31 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/338,992**

(22) Filed: **Dec. 18, 2008**

(65) **Prior Publication Data**

US 2009/0160590 A1 Jun. 25, 2009

Related U.S. Application Data

(63) Continuation-in-part of application No. 12/040,741, filed on Feb. 29, 2008.

(60) Provisional application No. 61/066,121, filed on Dec. 19, 2007.

(51) **Int. Cl.**
H01H 47/00 (2006.01)

(52) **U.S. Cl.** **361/144**; 361/143; 361/152

(58) **Field of Classification Search** 361/144
See application file for complete search history.

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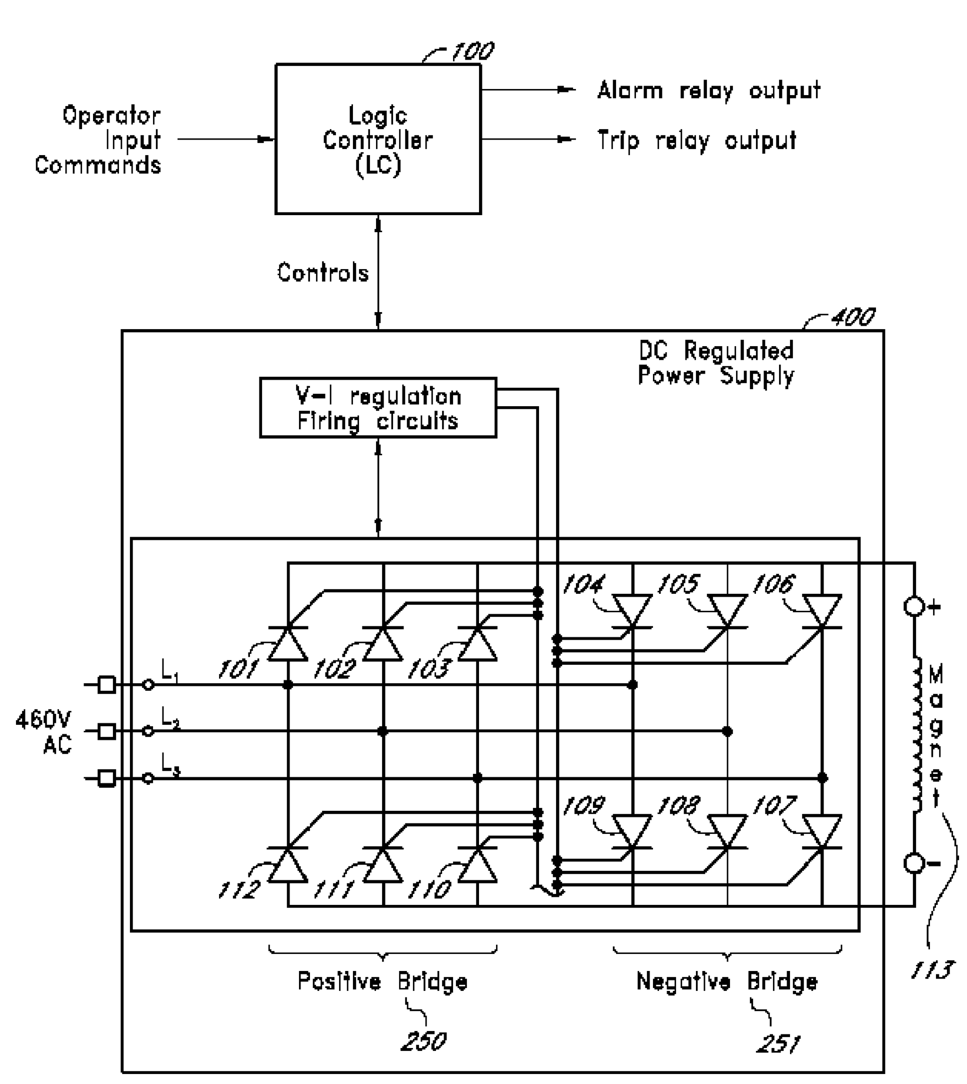
(57) **ABSTRACT**

A magnet controller supplied by an AC source controls a lifting magnet. Two bridges allow DC current to flow in both directions in the lifting magnet. During “Lift”, relatively high voltage is applied to the lifting magnet until it reaches its cold current. Then voltage is lowered. After a desired interval, once the magnet has had time to build its electromagnetic field, voltage is further reduced to prevent the magnet from overheating. The magnet lifting forced is maintained due to the magnetic circuit hysteresis. During “Drop”, reverse voltage is applied briefly to demagnetize the lifting magnet. At the end of the “Lift” and the “Drop”, most of the lifting magnet energy is returned to the line source. A logic controller controls current and voltage of the magnet and calculates the magnet’s temperature. In one embodiment, a “Sweep” switch is provided to allow reduction of the magnet power to prevent attraction to the bottom or walls of magnetic rail cars or containers.

15 Claims, 20 Drawing Sheets



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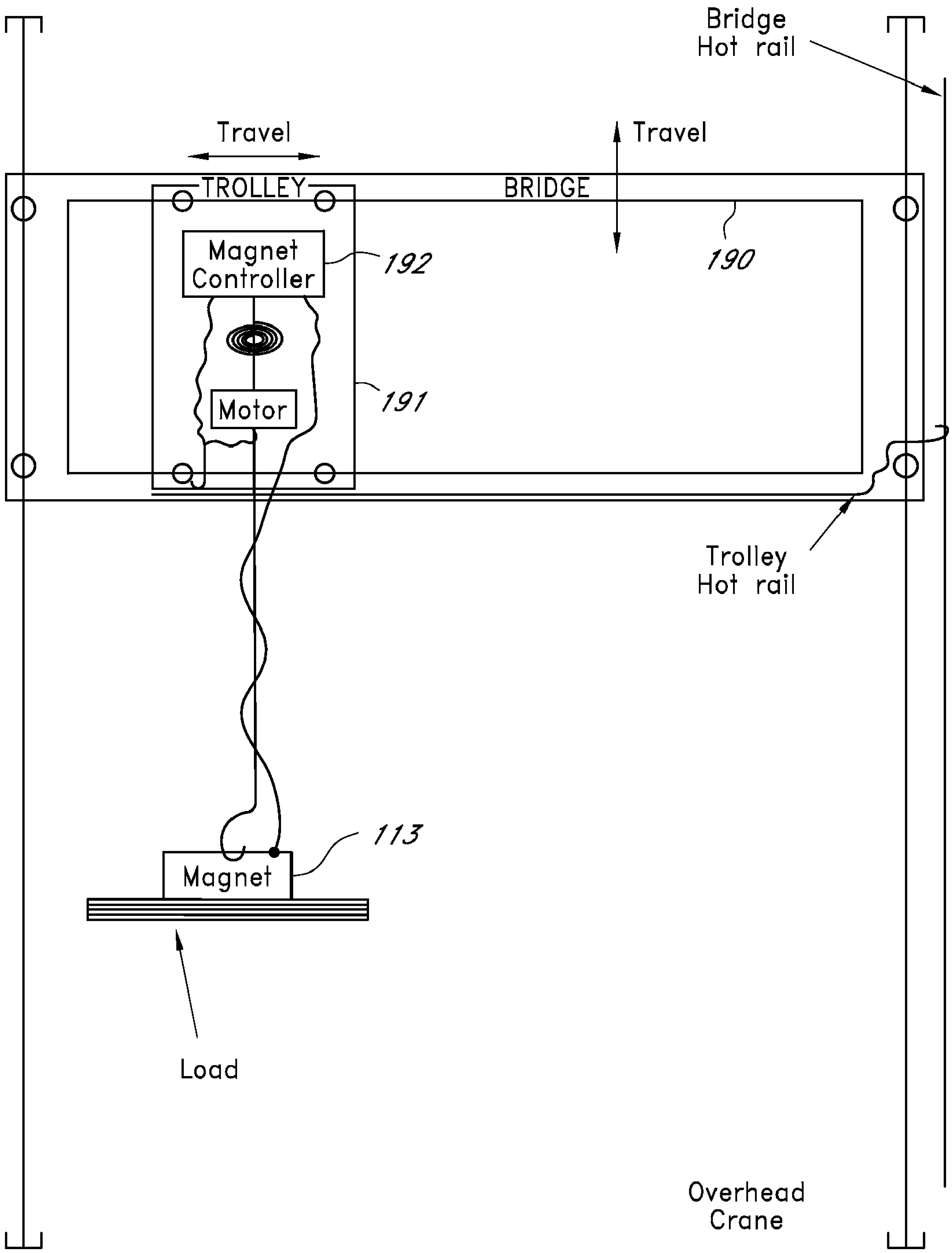

Bridge
Hot rail
Travel
Travel
TROLLEY
BRIDGE
Magnet
Controller
192
190
Motor
191
Trolley
Hot rail
113
Magnet
Load
Overhead
Crane

FIG. 1

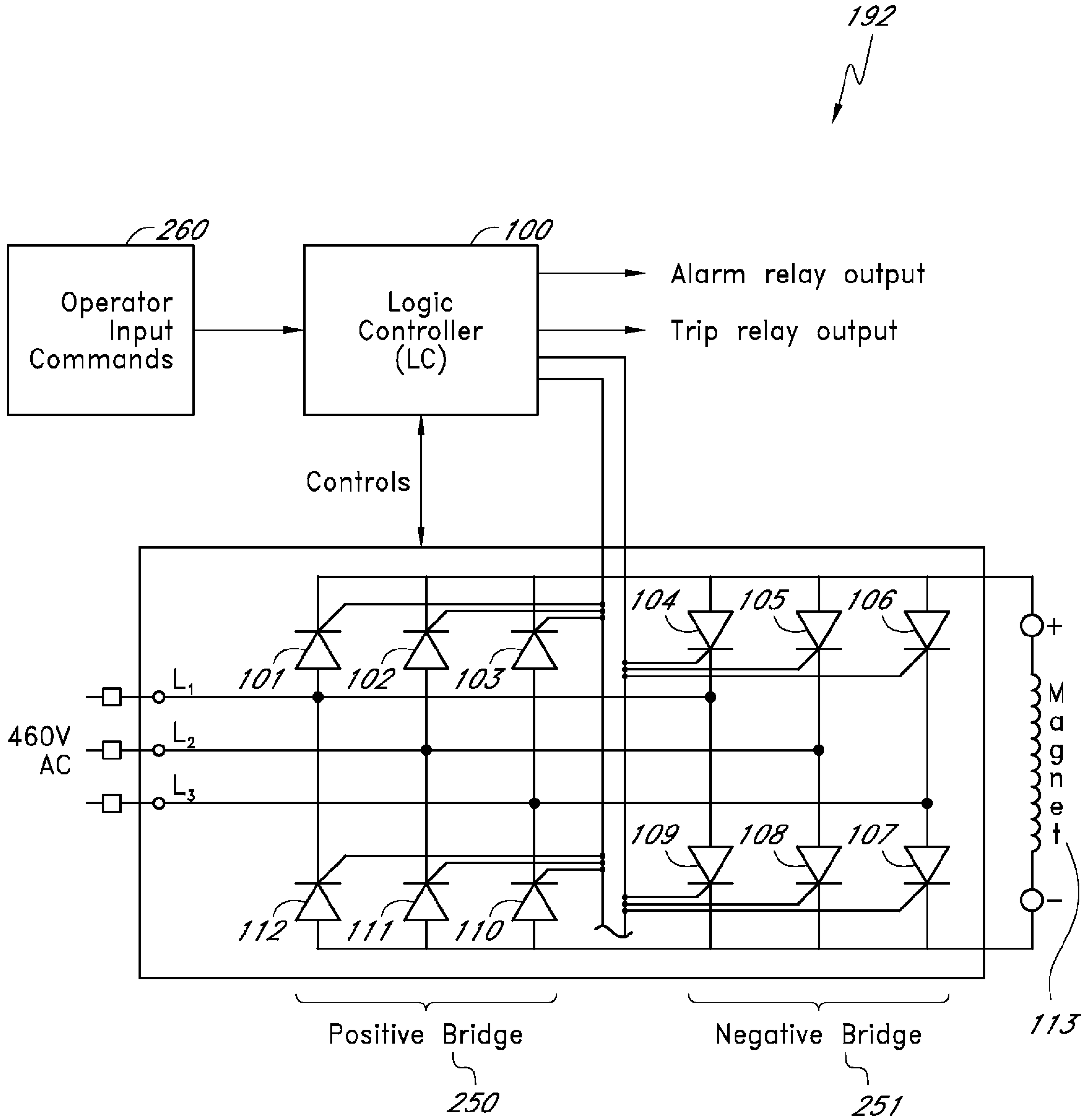

192
260
Operator Input Commands
100
Logic Controller (LC)
Alarm relay output
Trip relay output
Controls
460V AC
L1
L2
L3
101
102
103
104
105
106
107
108
109
110
111
112
Magnet
113
Positive Bridge
250
Negative Bridge
251

FIG. 2A

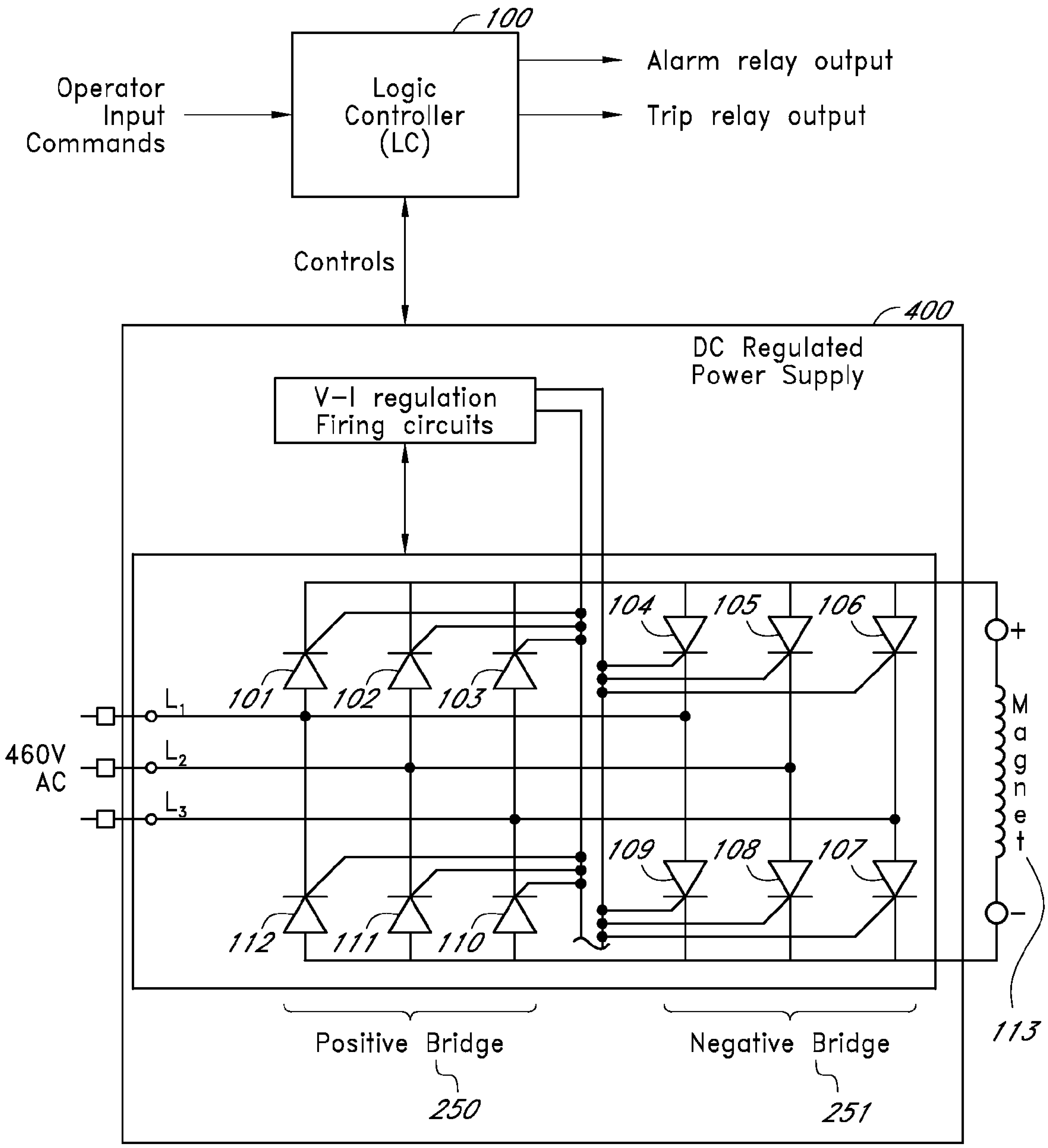

100
Operator
Input
Commands
Logic
Controller
(LC)
Alarm relay output
Trip relay output
Controls
400
DC Regulated
Power Supply
V-I regulation
Firing circuits
104
105
106
101
102
103
L1
L2
L3
460V
AC
109
108
107
112
111
110
+
−
Magnet
113
Positive Bridge
250
Negative Bridge
251

FIG. 2B

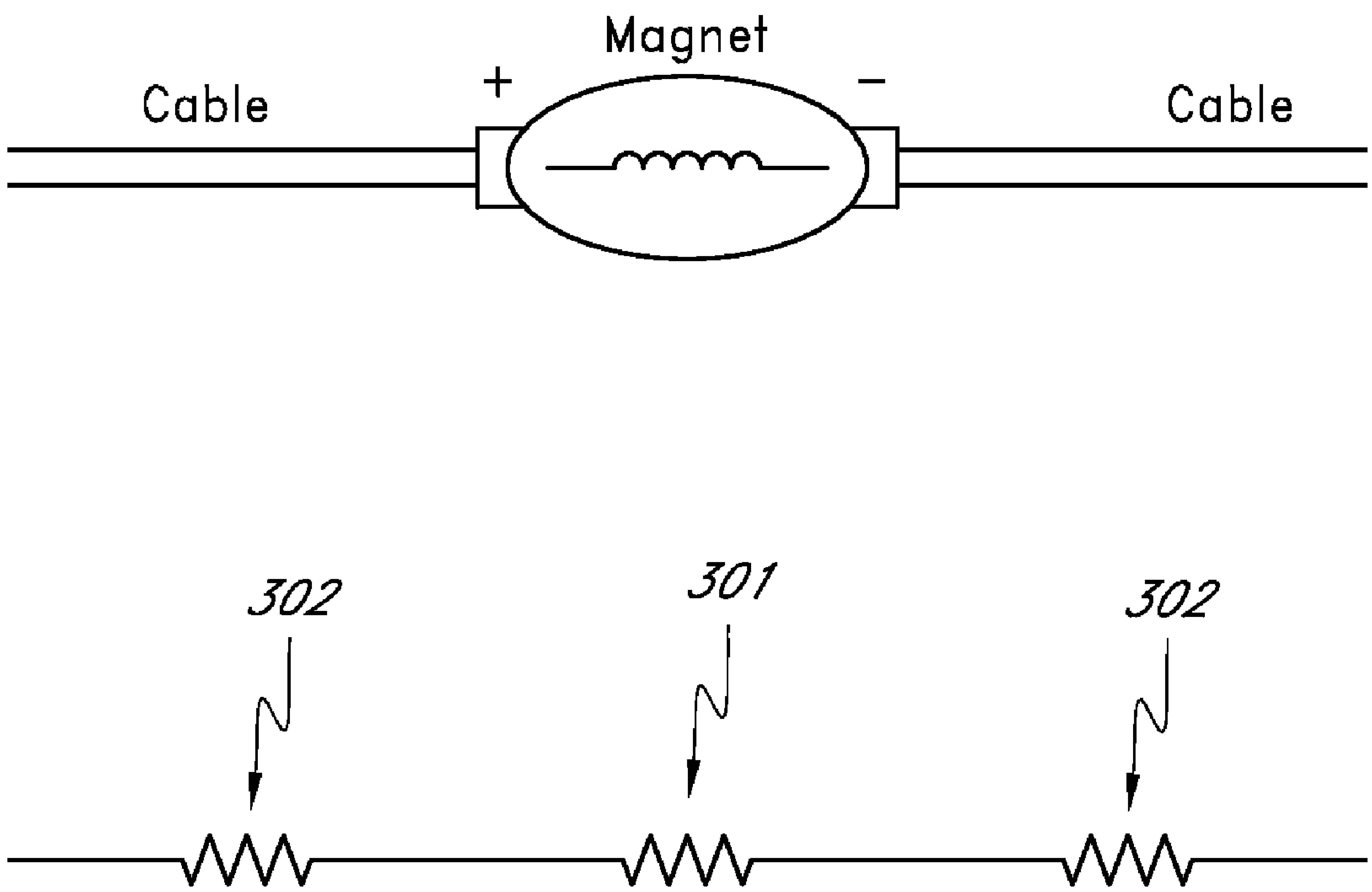


FIG. 3

DC Equivalent Circuit

FIG. 4A

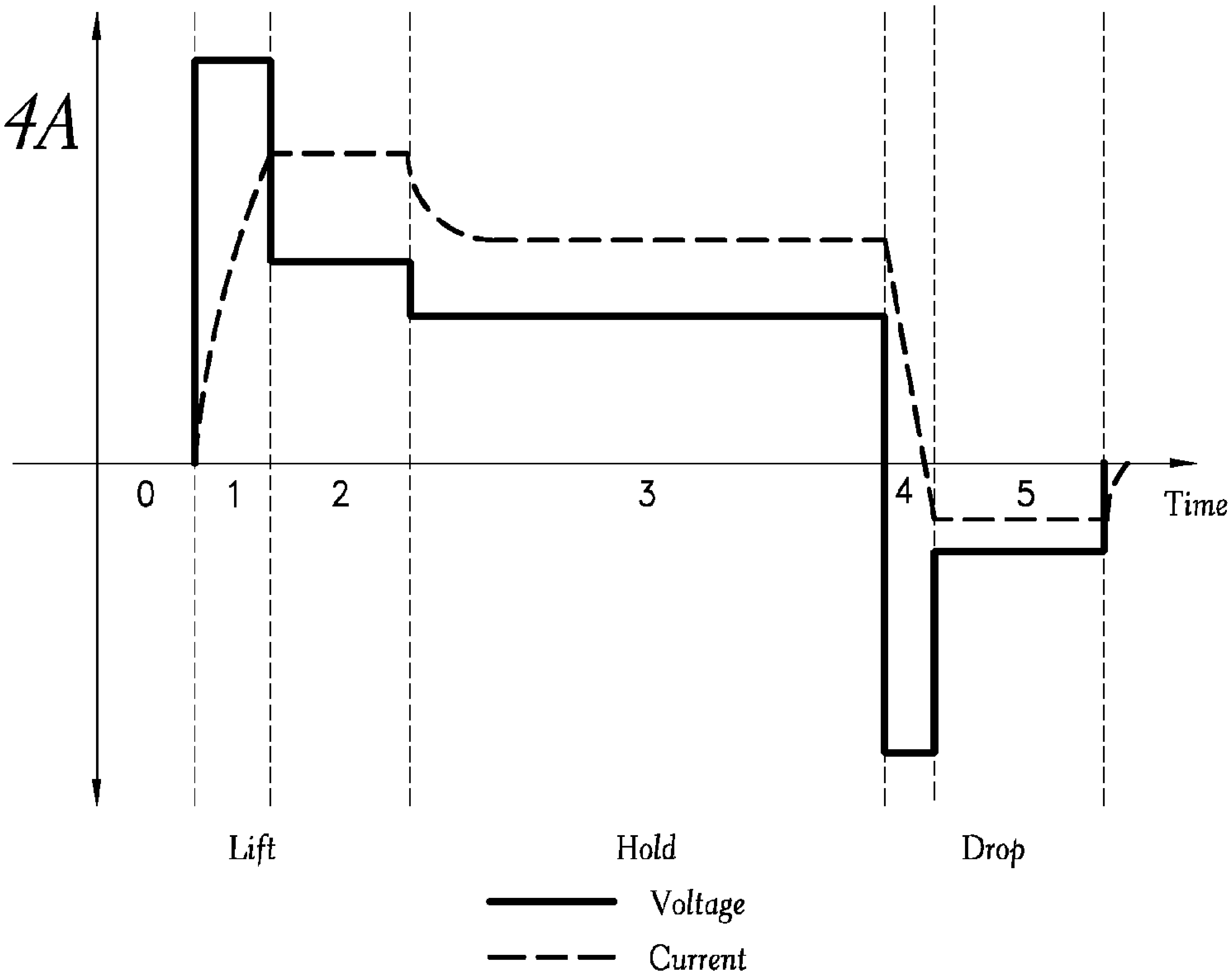
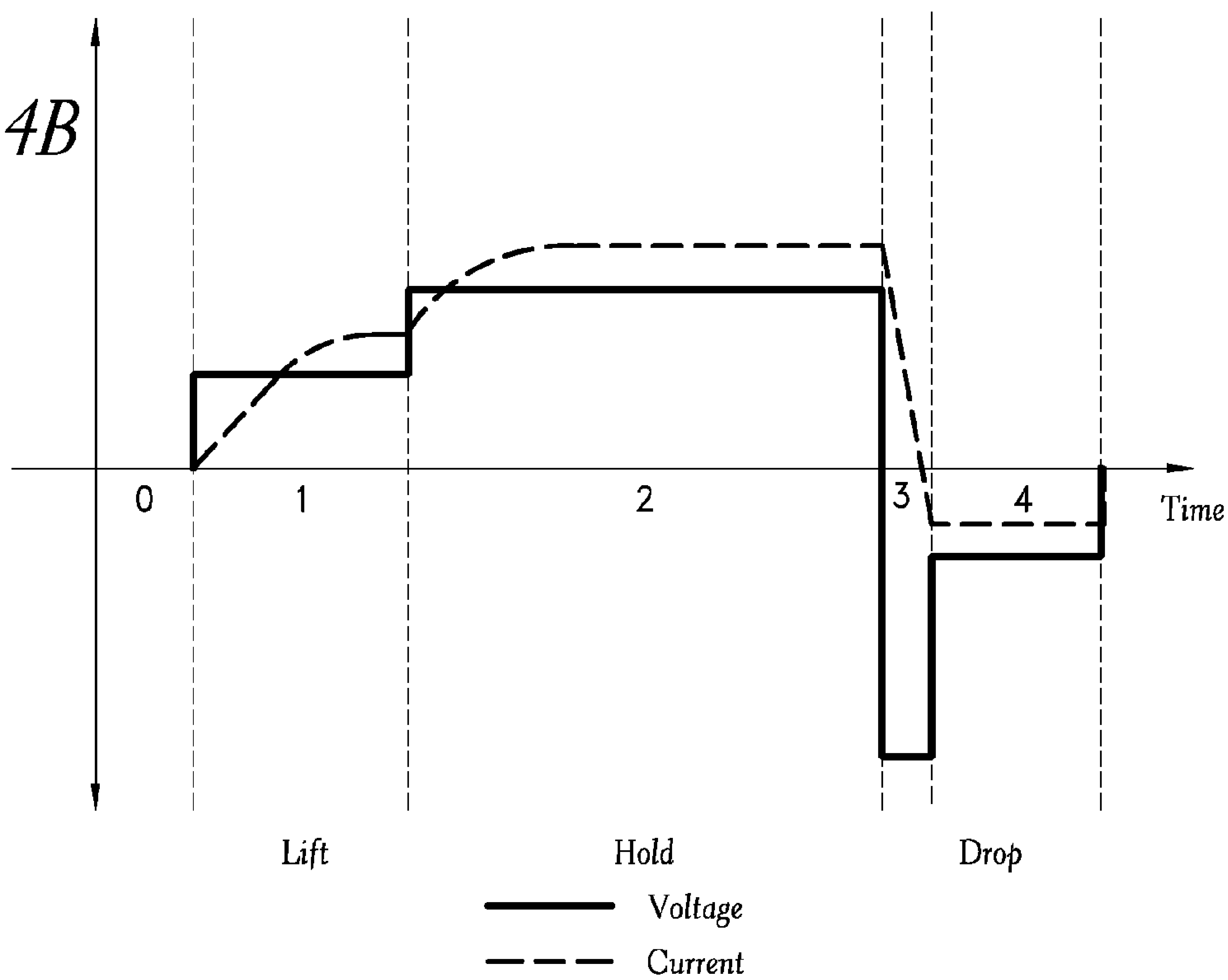

0
1
2
3
4
5
Time
Lift
Hold
Drop
Voltage
Current

FIG. 4B


0
1
2
3
4
Time
Lift
Hold
Drop
Voltage
Current

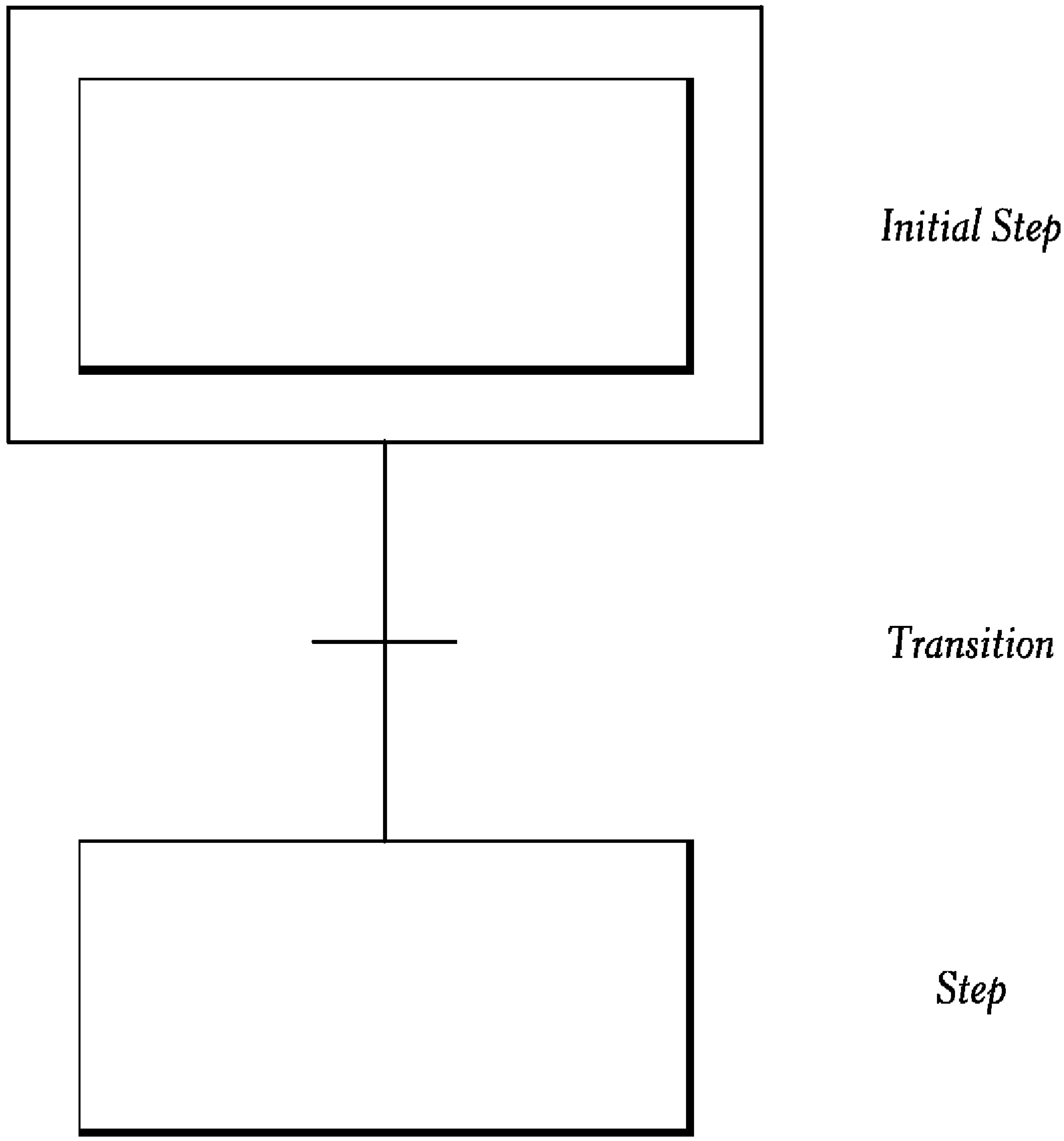


FIG. 5

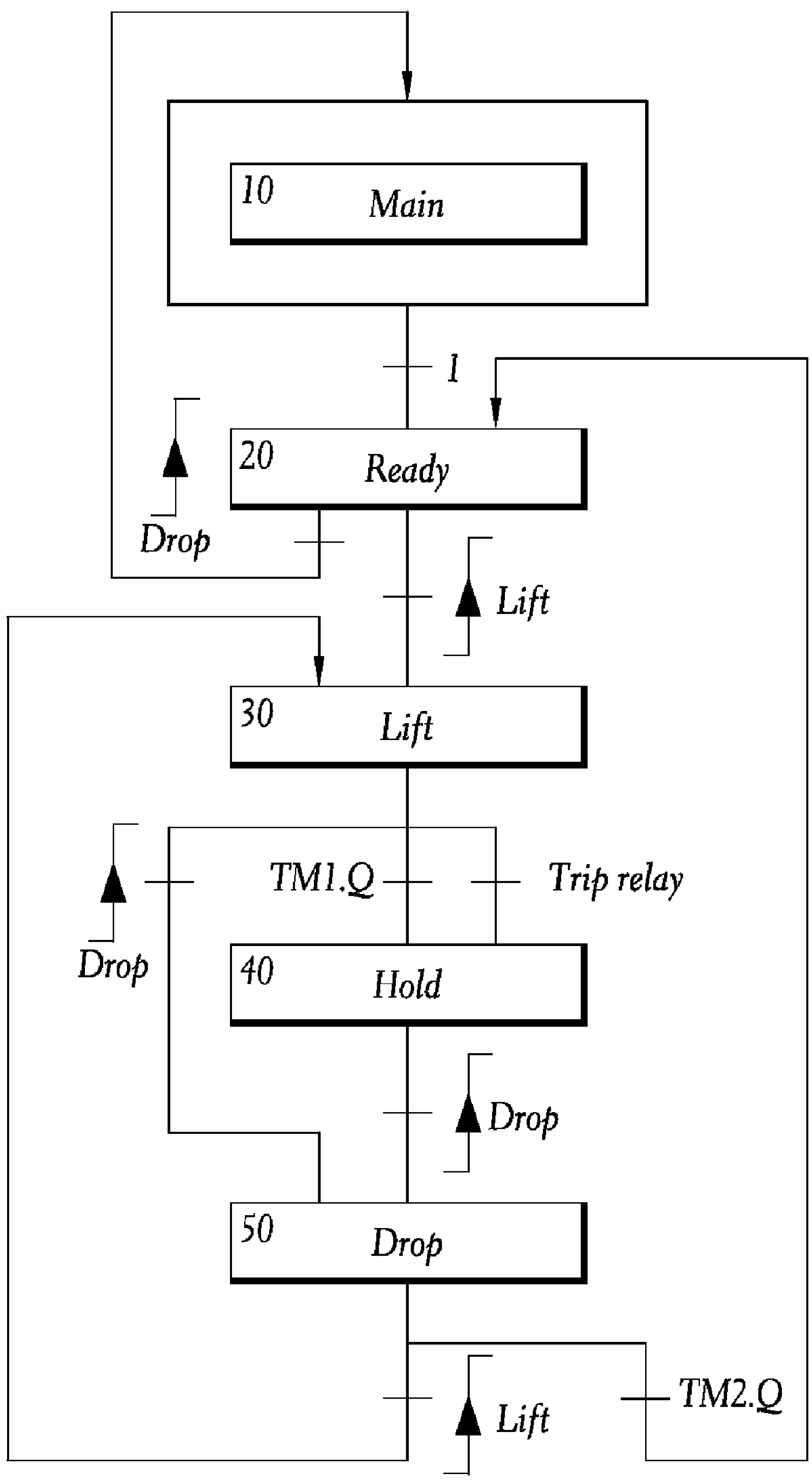


FIG. 6

Main SFC

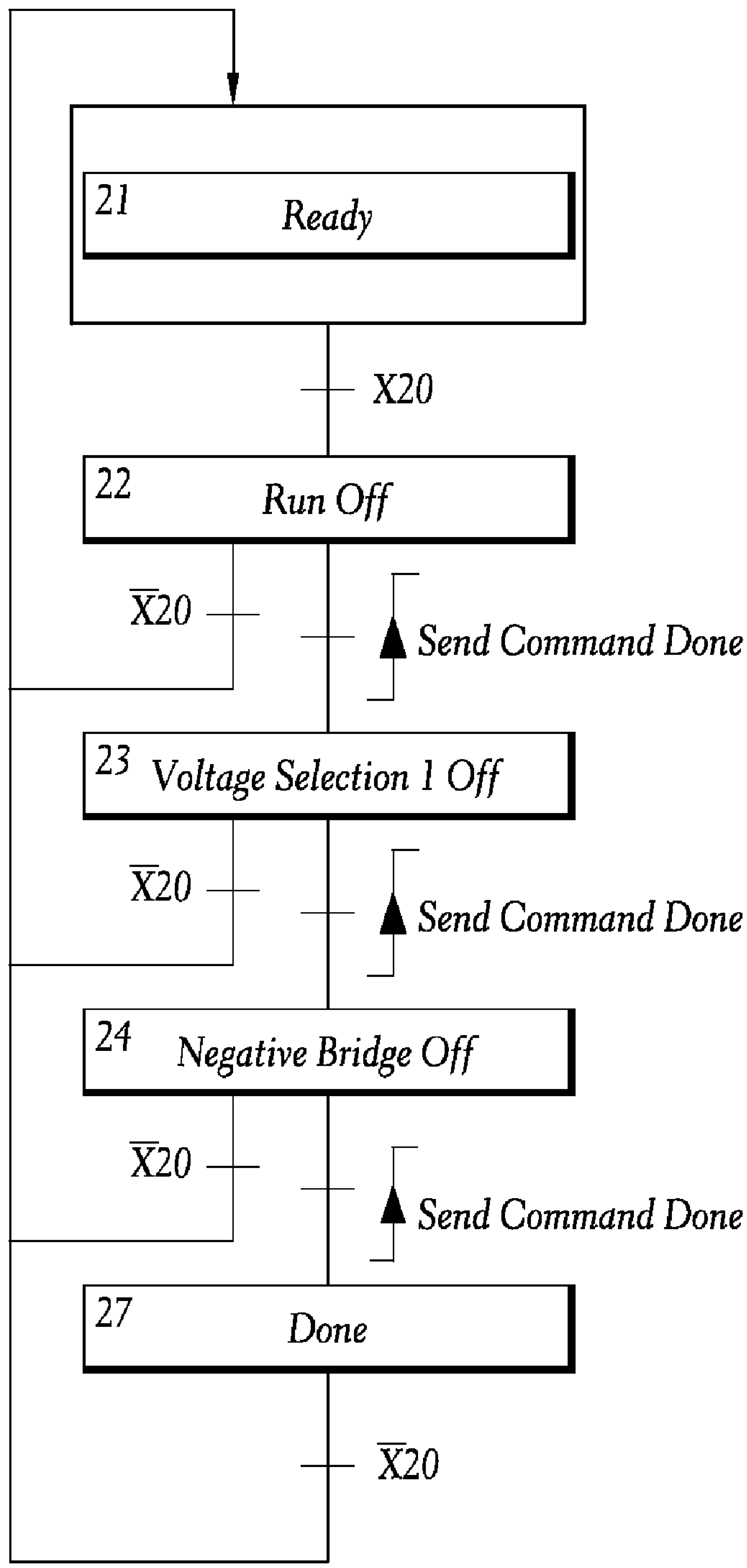


FIG. 7

Ready SFC

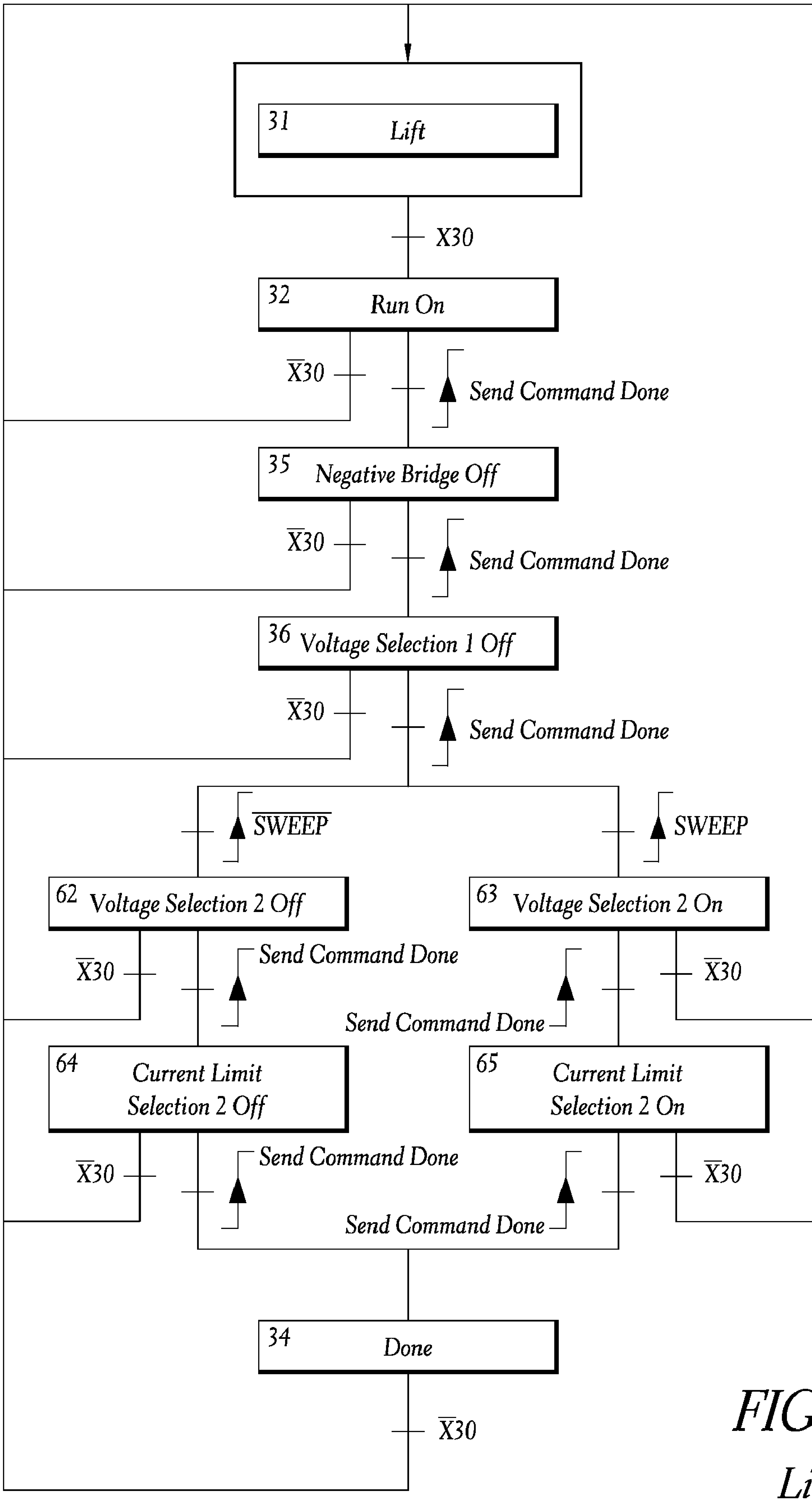


FIG. 8

Lift SFC

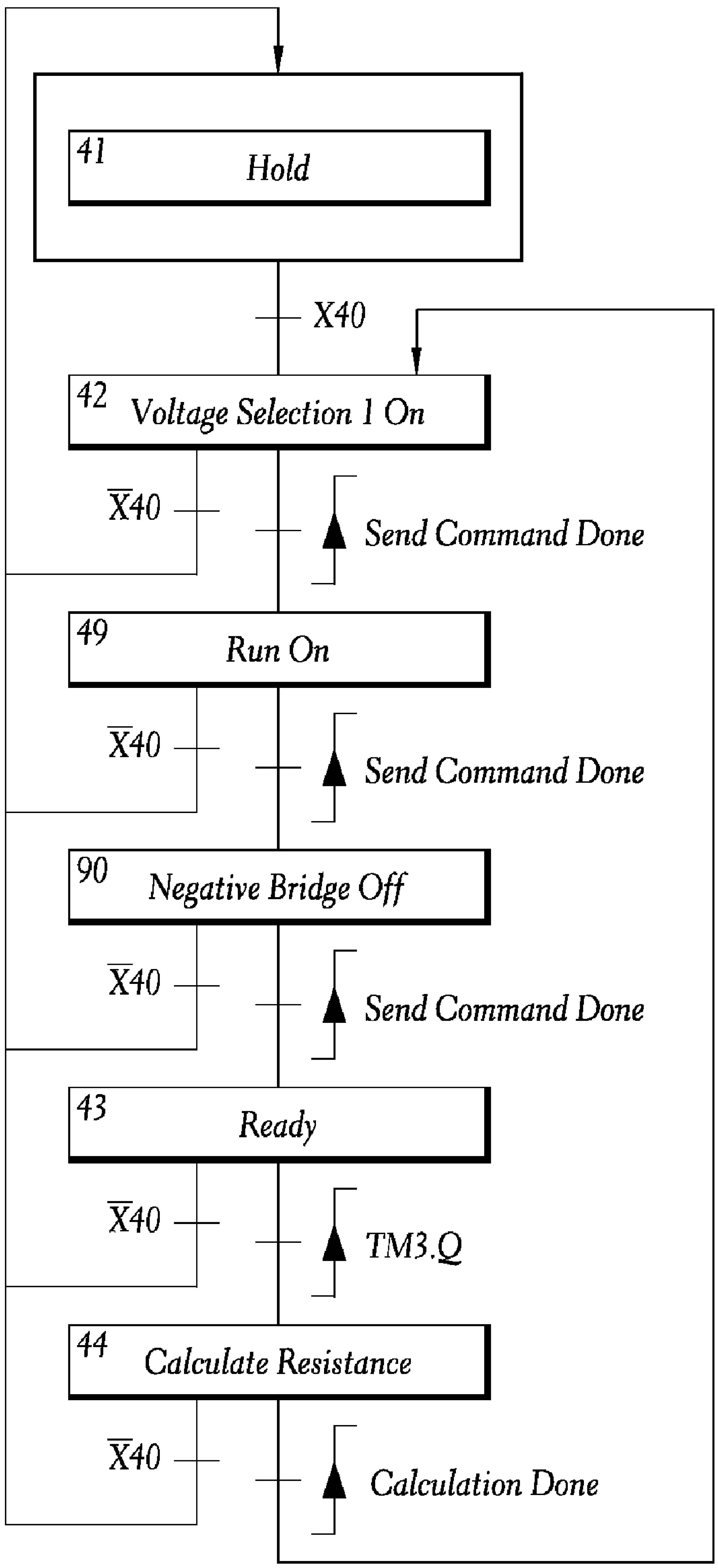


FIG. 9

Hold SFC

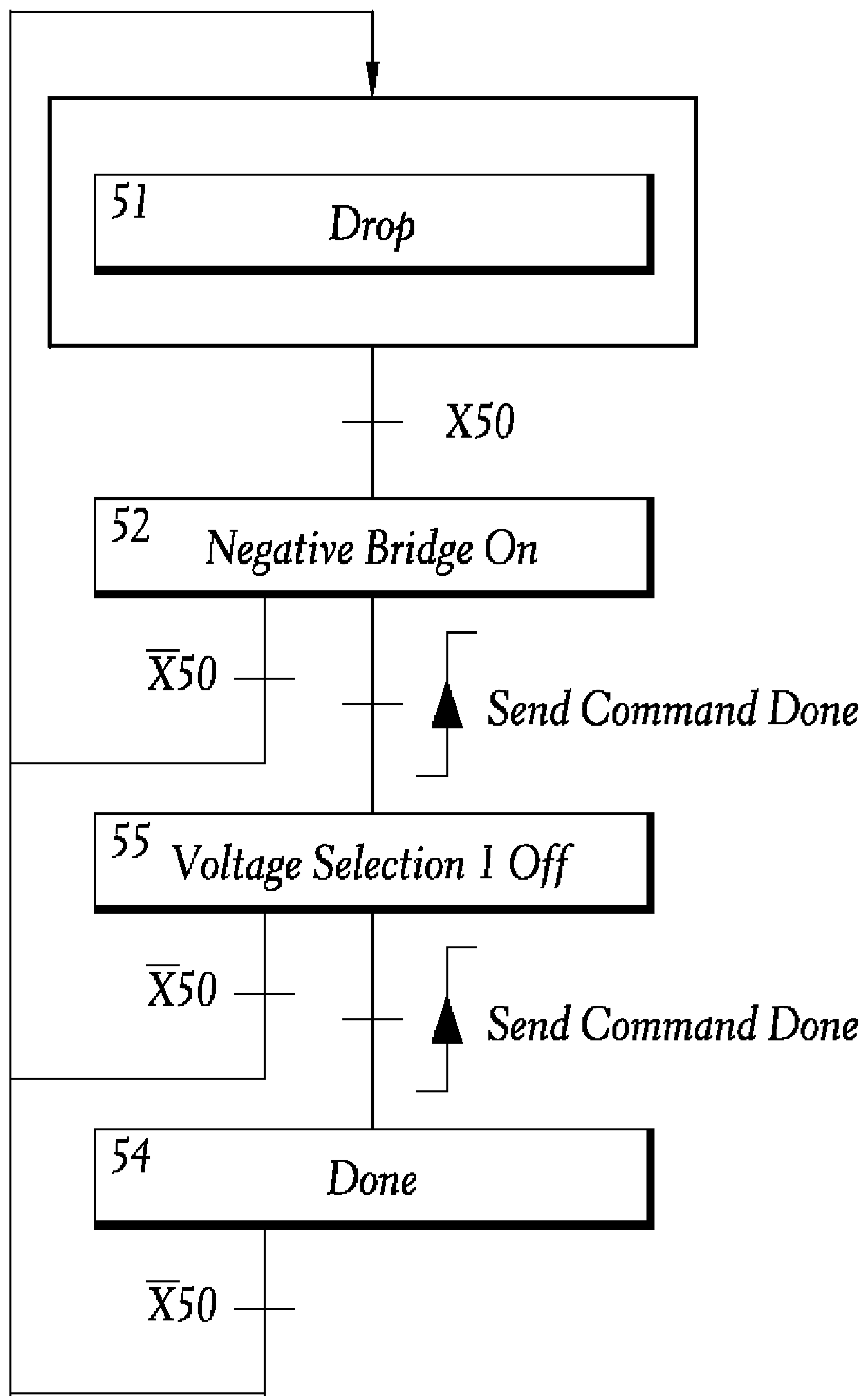


FIG. 10

Drop SFC

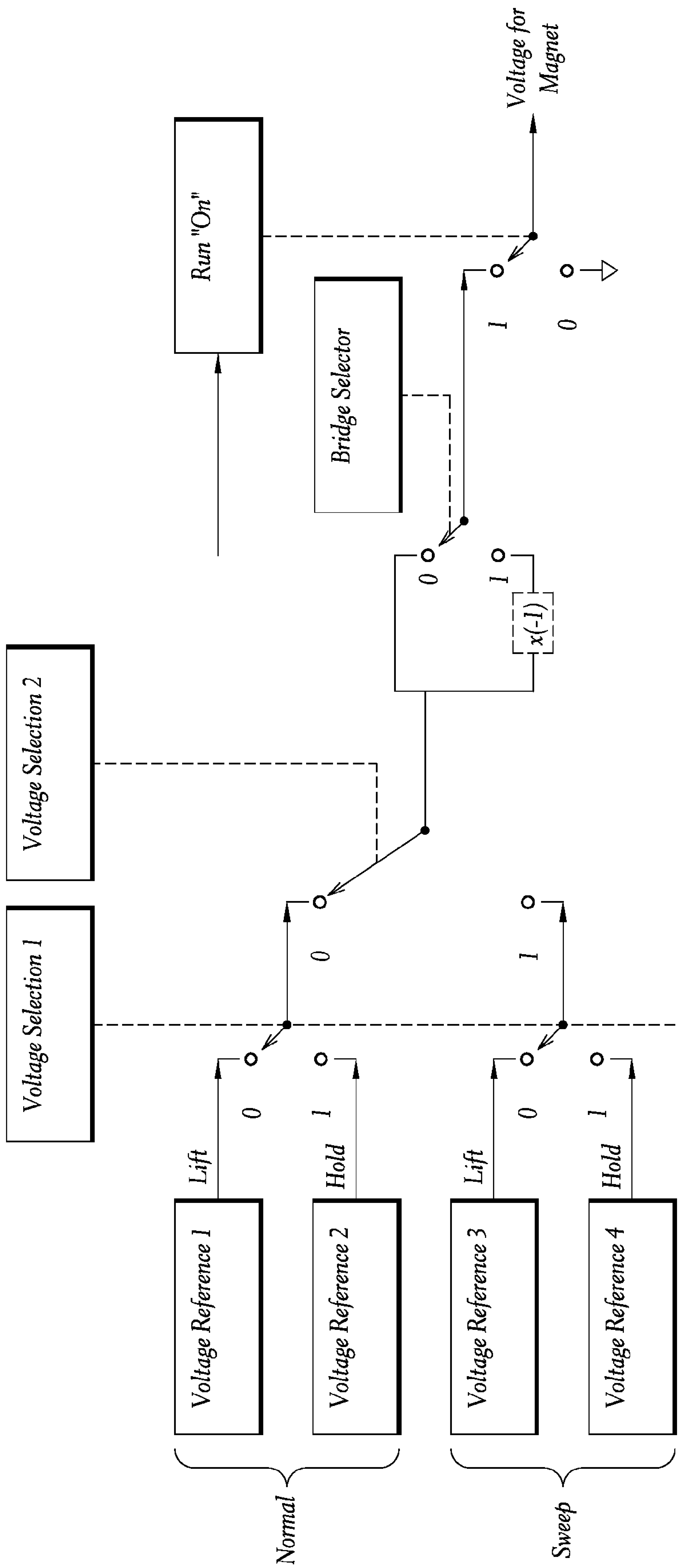


FIG. 11
DC Regulated Power Supply Voltage Selection

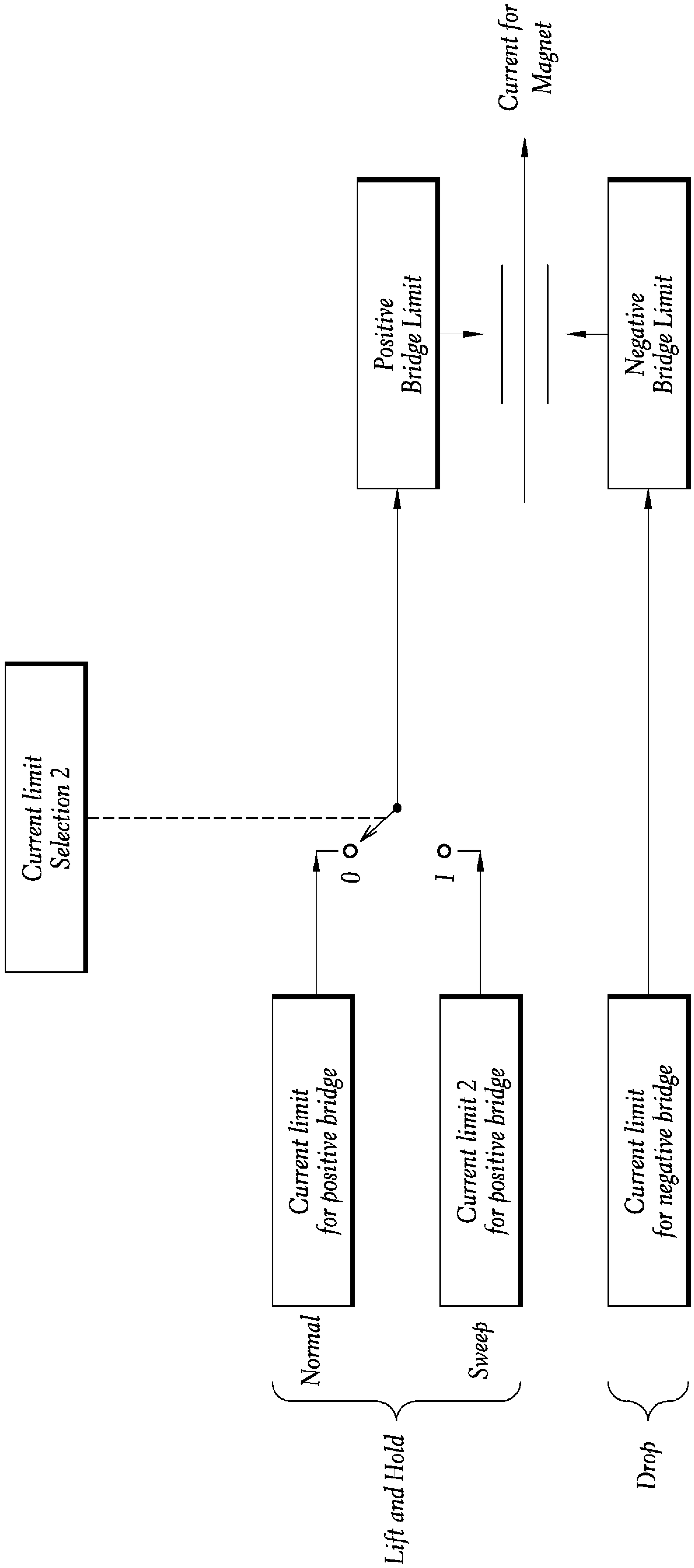
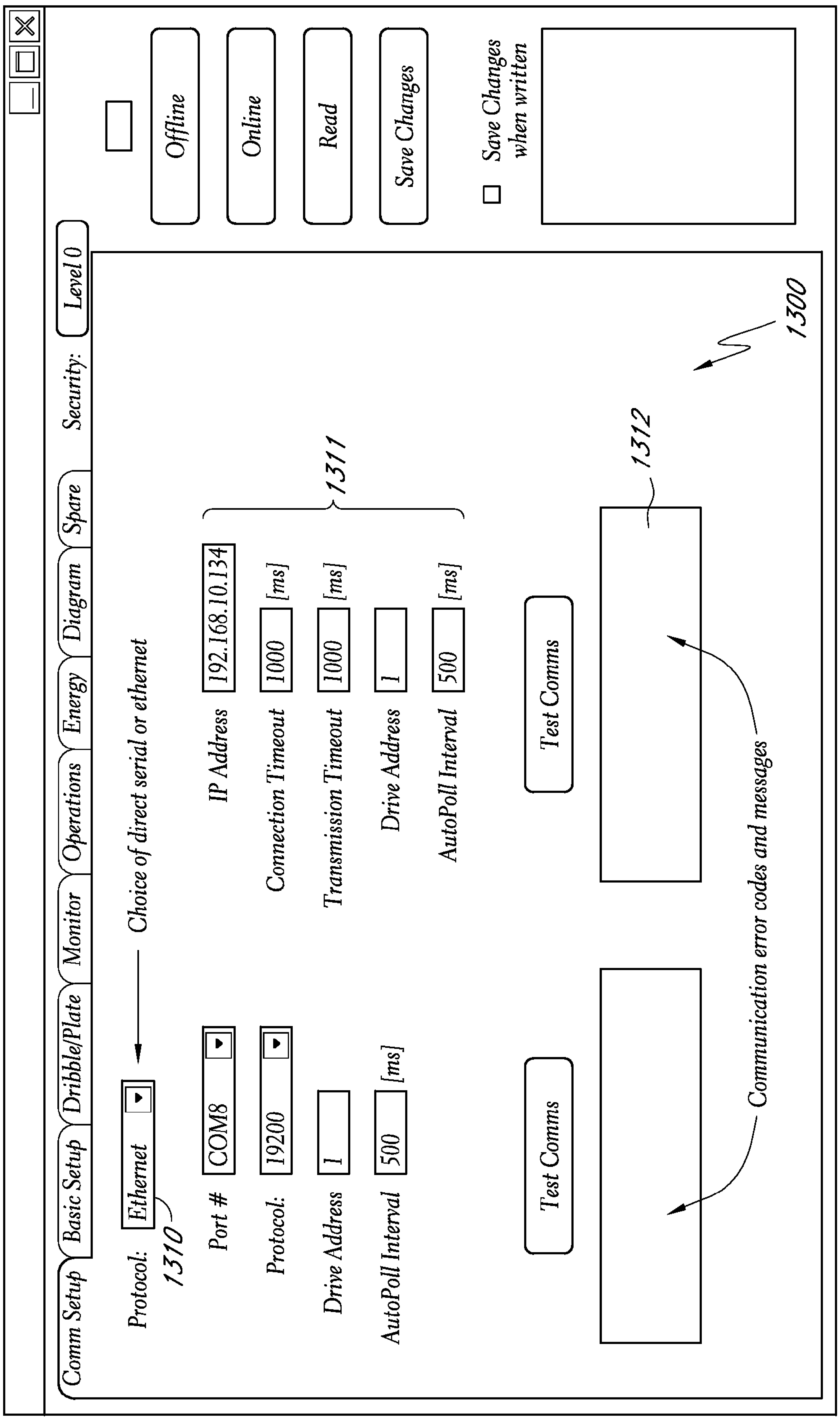


FIG. 12

DC Regulated Power Supply Current Selection



Comm Setup
Basic Setup
Dribble/Plate
Monitor
Operations
Energy
Diagram
Spare
Security:
Level 0
Offline
Online
Read
Save Changes
Save Changes when written
Protocol:
Ethernet
1310
Choice of direct serial or ethernet
Port #
COM8
Protocol:
19200
Drive Address
1
AutoPoll Interval
500
[ms]
IP Address
192.168.10.134
Connection Timeout
1000
[ms]
Transmission Timeout
1000
[ms]
Drive Address
1
AutoPoll Interval
500
[ms]
1311
Test Comms
Test Comms
1312
Communication error codes and messages
1300

FIG. 13

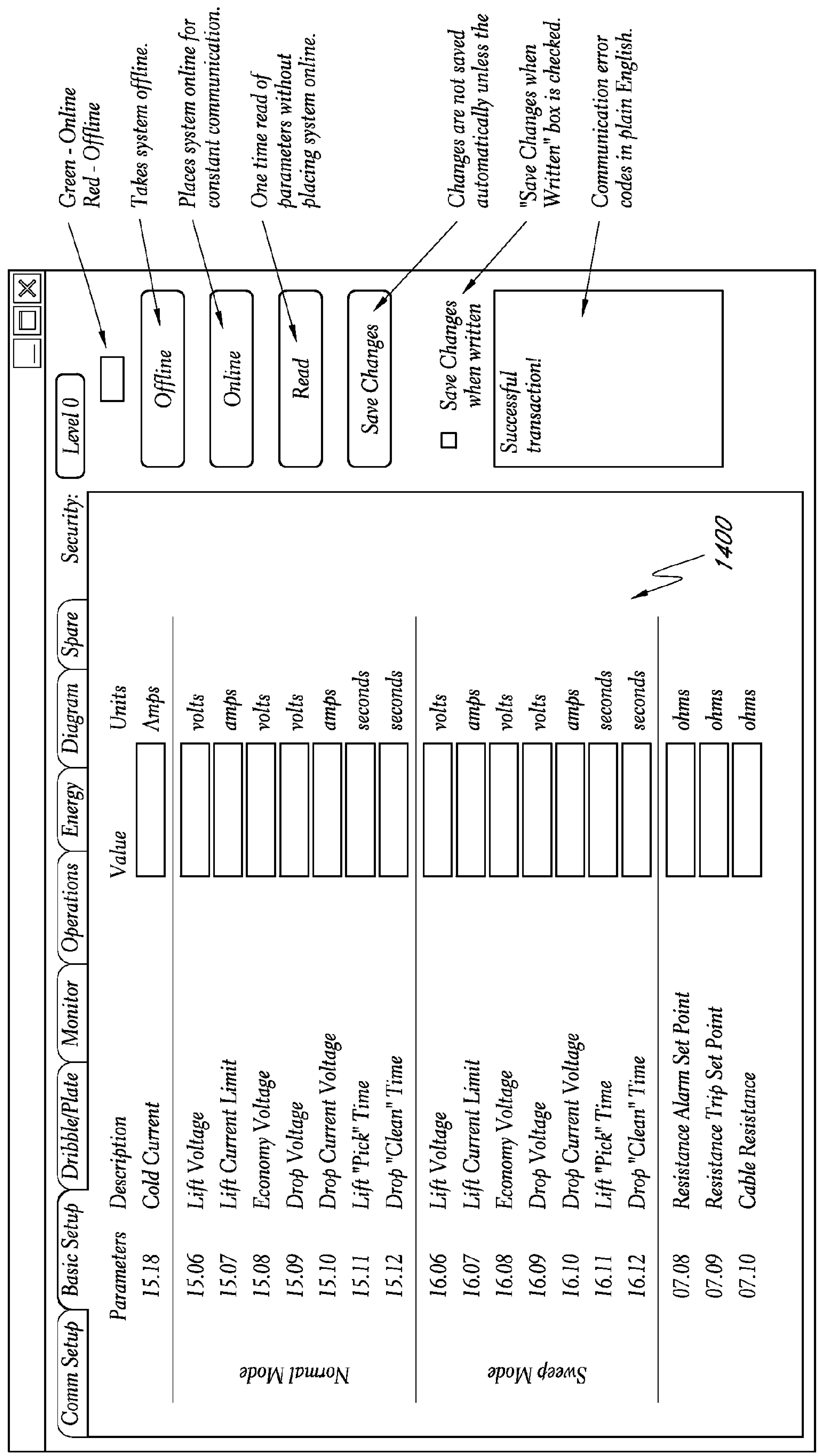

Green - Online
Red - Offline
Takes system offline.
Places system online for constant communication.
One time read of parameters without placing system online.
Changes are not saved automatically unless the "Save Changes when Written" box is checked.
Communication error codes in plain English.
Comm Setup
Basic Setup
Dribble/Plate
Monitor
Operations
Energy
Diagram
Spare
Security:
Level 0
Offline
Online
Read
Save Changes
Save Changes when written
Successful transaction!
Normal Mode
Sweep Mode
Parameters
Description
Value
Units
15.18
Cold Current
Amps
15.06
Lift Voltage
volts
15.07
Lift Current Limit
amps
15.08
Economy Voltage
volts
15.09
Drop Voltage
volts
15.10
Drop Current Voltage
amps
15.11
Lift "Pick" Time
seconds
15.12
Drop "Clean" Time
seconds
16.06
Lift Voltage
volts
16.07
Lift Current Limit
amps
16.08
Economy Voltage
volts
16.09
Drop Voltage
volts
16.10
Drop Current Voltage
amps
16.11
Lift "Pick" Time
seconds
16.12
Drop "Clean" Time
seconds
07.08
Resistance Alarm Set Point
ohms
07.09
Resistance Trip Set Point
ohms
07.10
Cable Resistance
ohms
1400

FIG. 14

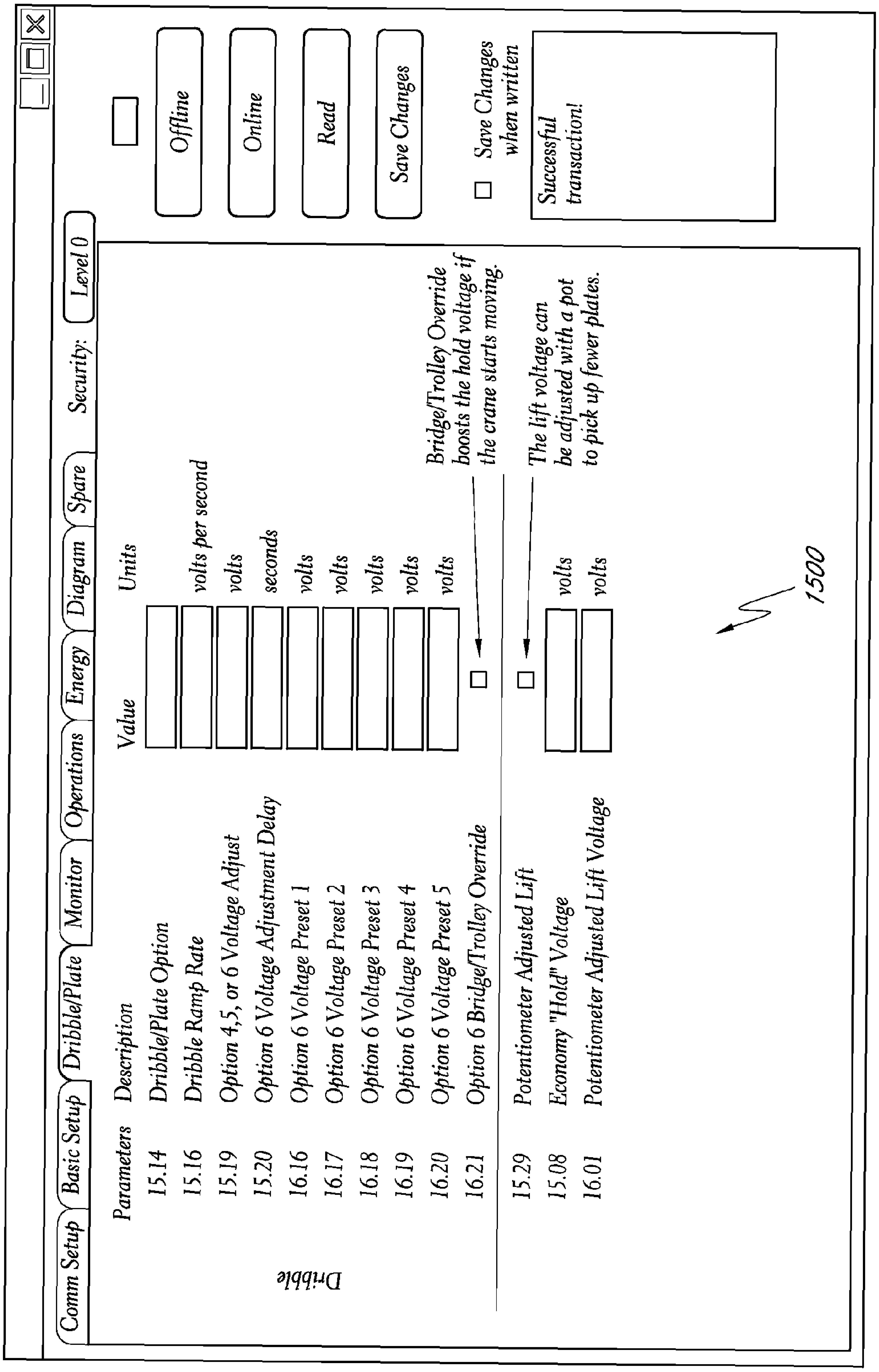

Comm Setup
Basic Setup
Dribble/Plate
Monitor
Operations
Energy
Diagram
Spare
Security:
Level 0
Dribble
Parameters
Description
Value
Units
15.14
Dribble/Plate Option
15.16
Dribble Ramp Rate
volts per second
15.19
Option 4,5, or 6 Voltage Adjust
volts
15.20
Option 6 Voltage Adjustment Delay
seconds
16.16
Option 6 Voltage Preset 1
volts
16.17
Option 6 Voltage Preset 2
volts
16.18
Option 6 Voltage Preset 3
volts
16.19
Option 6 Voltage Preset 4
volts
16.20
Option 6 Voltage Preset 5
volts
16.21
Option 6 Bridge/Trolley Override
Bridge/Trolley Override boosts the hold voltage if the crane starts moving.
15.29
Potentiometer Adjusted Lift
The lift voltage can be adjusted with a pot to pick up fewer plates.
15.08
Economy "Hold" Voltage
volts
16.01
Potentiometer Adjusted Lift Voltage
volts
Offline
Online
Read
Save Changes
Save Changes when written
Successful transaction!
1500

FIG. 15

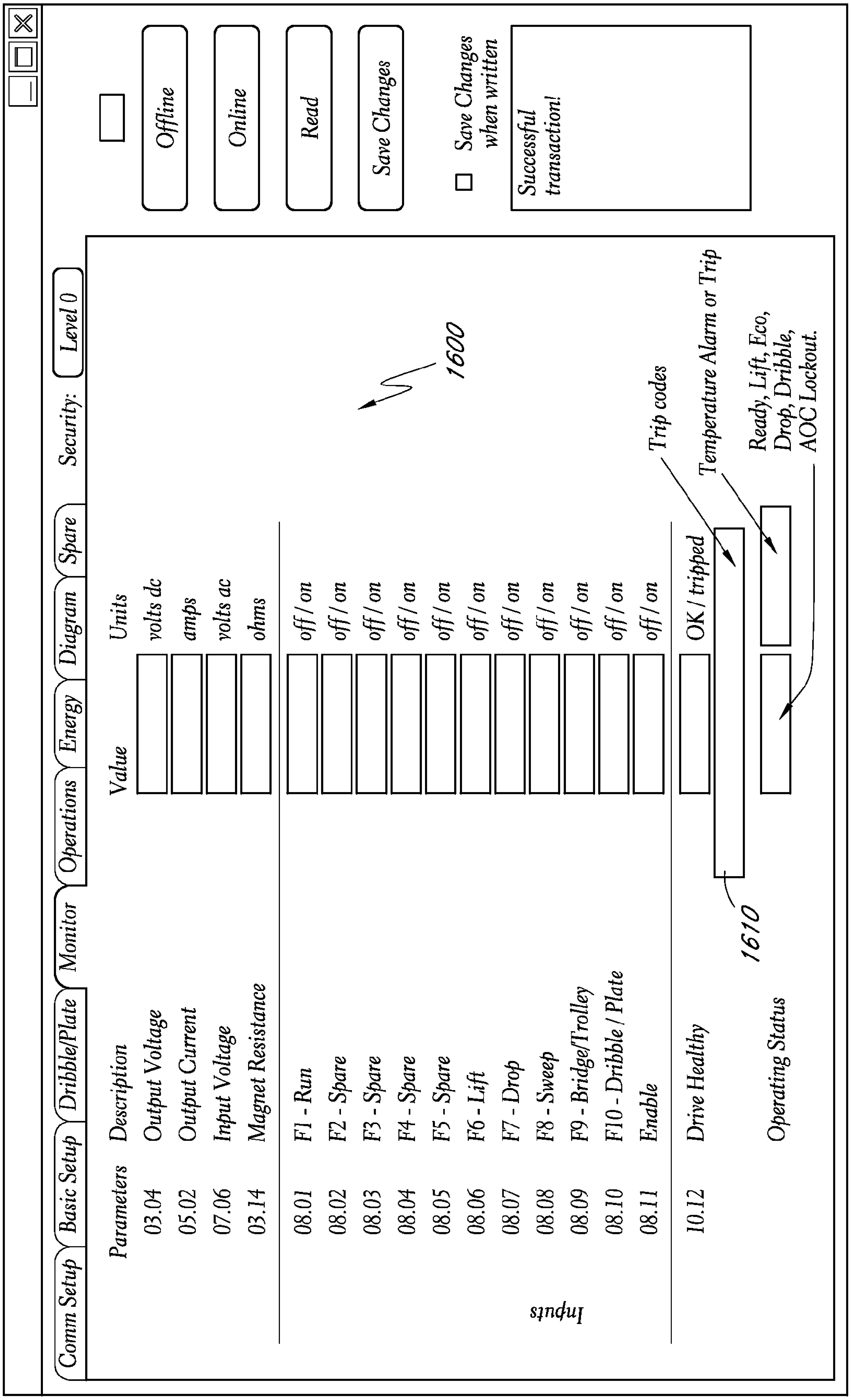
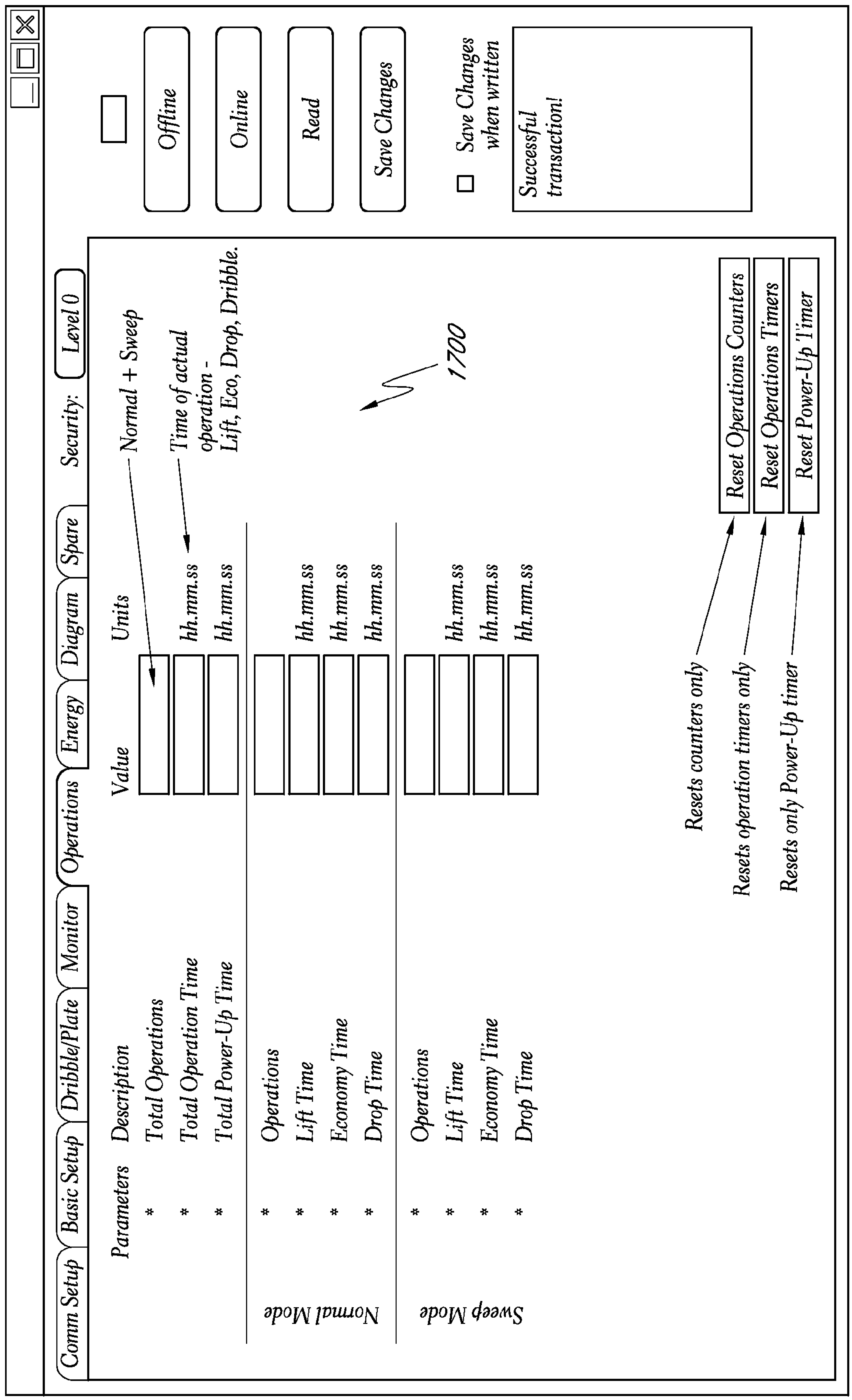

Comm Setup
Basic Setup
Dribble/Plate
Monitor
Operations
Energy
Diagram
Spare
Security:
Level 0
Offline
Online
Read
Save Changes
Save Changes when written
Successful transaction!
1600
Inputs
Parameters
Description
Value
Units
03.04
Output Voltage
volts dc
05.02
Output Current
amps
07.06
Input Voltage
volts ac
03.14
Magnet Resistance
ohms
08.01
F1 - Run
off / on
08.02
F2 - Spare
off / on
08.03
F3 - Spare
off / on
08.04
F4 - Spare
off / on
08.05
F5 - Spare
off / on
08.06
F6 - Lift
off / on
08.07
F7 - Drop
off / on
08.08
F8 - Sweep
off / on
08.09
F9 - Bridge/Trolley
off / on
08.10
F10 - Dribble / Plate
off / on
08.11
Enable
off / on
10.12
Drive Healthy
OK / tripped
Trip codes
Temperature Alarm or Trip
Operating Status
Ready, Lift, Eco, Drop, Dribble, AOC Lockout.
1610

FIG. 16



Comm Setup
Basic Setup
Dribble/Plate
Monitor
Operations
Energy
Diagram
Spare
Security:
Level 0
Offline
Online
Read
Save Changes
Save Changes when written
Successful transaction!
Parameters
Description
Value
Units
Total Operations
Total Operation Time
Total Power-Up Time
hh.mm.ss
hh.mm.ss
Normal Mode
Operations
Lift Time
Economy Time
Drop Time
hh.mm.ss
hh.mm.ss
hh.mm.ss
Sweep Mode
Operations
Lift Time
Economy Time
Drop Time
hh.mm.ss
hh.mm.ss
hh.mm.ss
Normal + Sweep
Time of actual operation - Lift, Eco, Drop, Dribble.
1700
Reset Operations Counters
Reset Operations Timers
Reset Power-Up Timer
Resets counters only
Resets operation timers only
Resets only Power-Up timer

FIG. 17

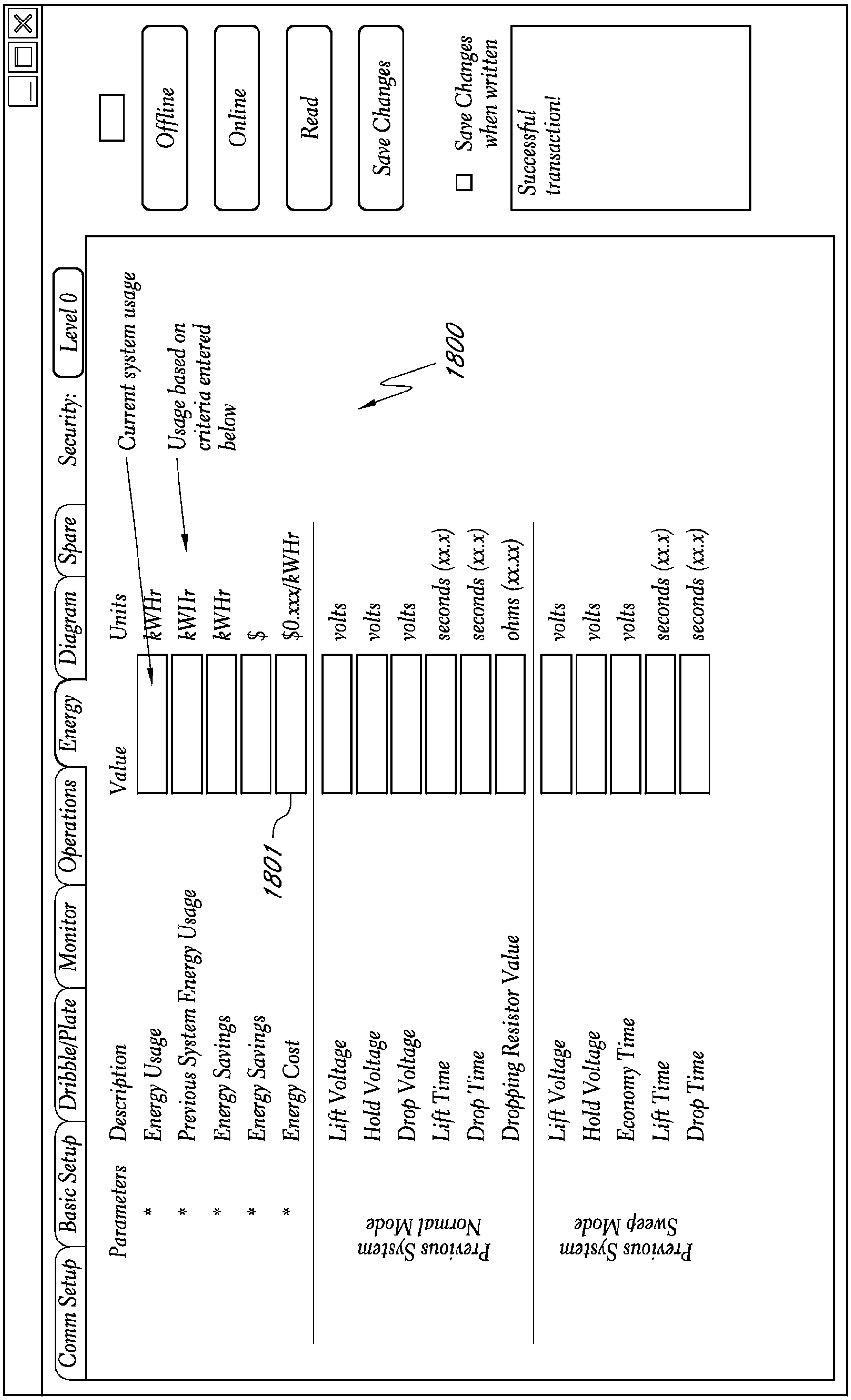
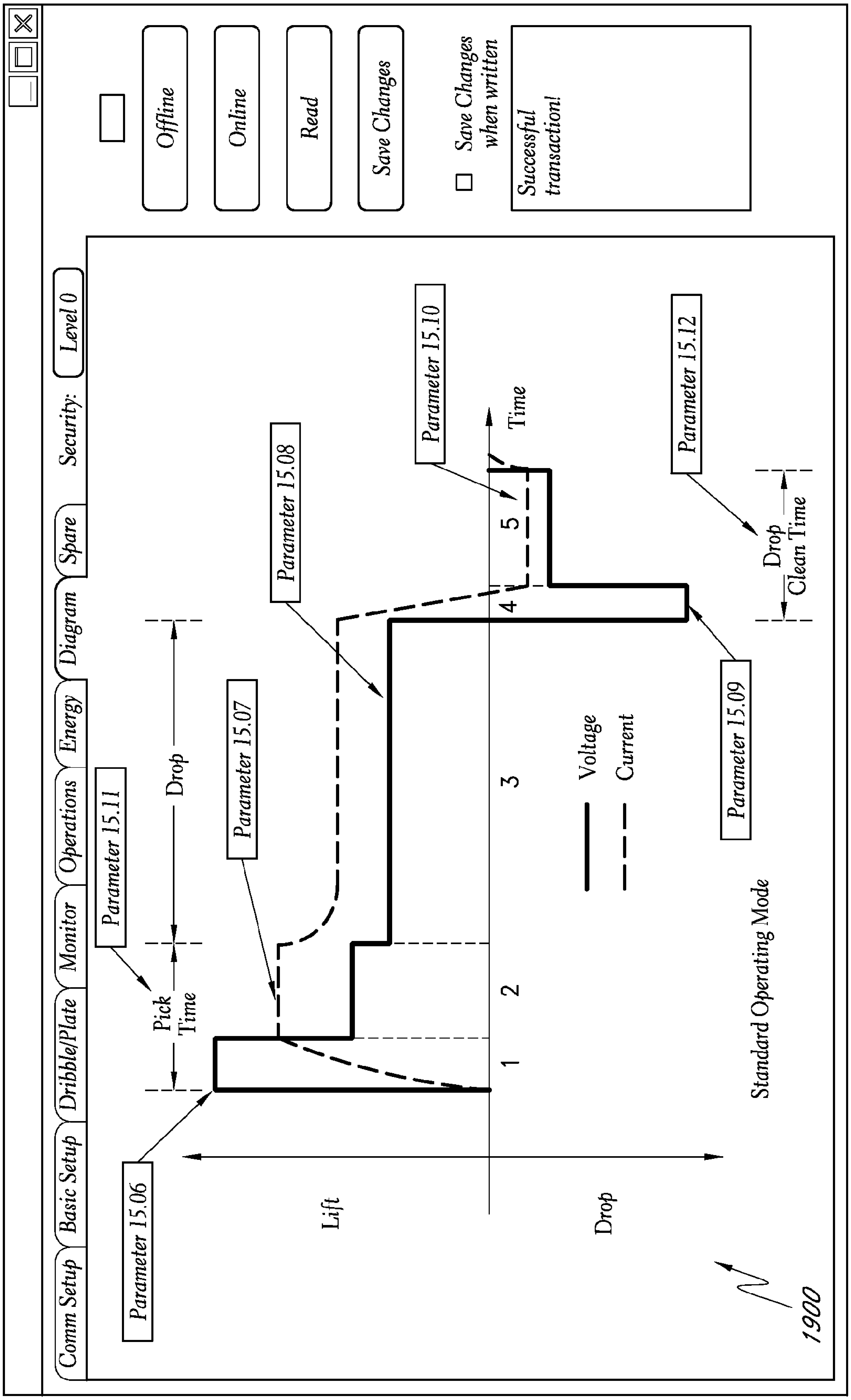

Comm Setup
Basic Setup
Dribble/Plate
Monitor
Operations
Energy
Diagram
Spare
Security:
Level 0
Parameters
Description
Value
Units
Energy Usage
kWHr
Previous System Energy Usage
kWHr
Energy Savings
kWHr
Energy Savings
$
Energy Cost
$0.xxx/kWHr
Current system usage
Usage based on criteria entered below
1801
1800
Previous System Normal Mode
Lift Voltage
volts
Hold Voltage
volts
Drop Voltage
volts
Lift Time
seconds (xx.x)
Drop Time
seconds (xx.x)
Dropping Resistor Value
ohms (xx.xx)
Previous System Sweep Mode
Lift Voltage
volts
Hold Voltage
volts
Economy Time
volts
Lift Time
seconds (xx.x)
Drop Time
seconds (xx.x)
Offline
Online
Read
Save Changes
Save Changes when written
Successful transaction!

FIG. 18



Offline
Online
Read
Save Changes
Save Changes when written
Successful transaction!
Comm Setup
Basic Setup
Dribble/Plate
Monitor
Operations
Energy
Diagram
Spare
Security:
Level 0
Parameter 15.06
Parameter 15.11
Parameter 15.07
Parameter 15.08
Parameter 15.10
Parameter 15.12
Parameter 15.09
Pick Time
Drop
Drop Clean Time
Time
1
2
3
4
5
Lift
Drop
Voltage
Current
Standard Operating Mode
1900

FIG. 19

METHOD AND APPARATUS FOR CONTROLLING A LIFTING MAGNET SUPPLIED WITH AN AC SOURCE

REFERENCE TO RELATED APPLICATIONS

The present application is a continuation-in-part of claims priority from U.S. Application No. 61/066,121, filed Dec. 19, 2007, titled "METHOD FOR CONTROLLING A LIFTING MAGNET SUPPLIED WITH AN AC SOURCE," and a continuation-in-part of claims priority from U.S. application Ser. No. 12/040,741, filed Feb. 29, 2008, titled "METHOD AND APPARATUS FOR CONTROLLING A LIFTING MAGNET SUPPLIED WITH AN AC SOURCE", the entire contents of which is hereby incorporated by reference.

BACKGROUND

1. Field of the Invention

The present invention relates to a method and apparatus for controlling a lifting magnet of a materials handling machine for which the source of electrical power is an AC power source.

2. Prior Art

Lifting magnets are commonly attached to hoists to load, unload, and otherwise move scrap steel and other ferrous metals. For many years, cranes were designed to be powered by DC sources, and therefore systems used to control lifting magnets were designed to be powered by DC as well. When using a hoist, due to the nature of the overhauling load, the torque and speed of the hoist motor need to be controlled. The traditional approach was to control the DC motor torque and speed by selecting resistors in series with the DC motor field and armature windings by means of contactors. In recent years, with the advance of electronic technology in the field of motor control, systems used to control lifting magnets, namely cranes, are now designed to be powered by AC sources. Cranes are now equipped with adjustable-frequency drives, commonly referred to as AC drives, which can accurately control the speed and torque of AC induction motors. The use of AC supplies removes the costs of installing and maintaining large AC-to-DC rectifiers, of replacing DC contactor tips, and of maintaining DC motor brushes and collectors. However, in order to use a lifting magnet on one of the new AC supplied cranes, a rectifier needs to be added to the crane. The rectifier that needs to be added to the crane is generally composed of a three-phase voltage step-down transformer connected to a six-diode bridge rectifier. The rectifier that is added to the crane is either mounted on the crane itself, where the rectifier becomes a weight constraint and an obstruction, or the rectifier is mounted elsewhere in the plant, in which case additional hot rails are required along the bridge and trolley in order for the DC electrical power to reach the DC-supplied magnet controller.

While lifting magnets have been in common use for many years, the systems used to control these lifting magnets remain relatively primitive. During the "Lift", a DC current energizes the lifting magnet in order to attract and retain the magnetic materials to be displaced. When the materials need to be separated from the lifting magnet, most of the controllers automatically apply a reversed voltage across the lifting magnet for a short period of time to allow the consequently reversed current to reach a fraction of the "Lift" current. The phase during which there is a reversed voltage applied across the magnet is known as the "Drop" phase, during which a magnetic field in the lifting magnet of the same magnitude but in an opposite direction of the residual magnetic field is produced such that the two fields cancel each other. When the lifting magnet is free of residual magnetic field, the scrap metal detaches freely from the lifting magnet. This metal detachment is known as a "Clean Drop".

Some control systems operate to selectively open and close contacts that, when closed, complete a "Lift" or "Drop" circuit between the DC generator and the lifting magnet. At the end of the "Lift", which is called the "discharge" and at the end of the "Drop", which is called the "secondary discharge", these systems generally use either a resistor or a varistor to discharge the lifting magnet's energy. The higher the resistor's resistance value or varistor breakdown voltage, the faster the lifting magnet discharges, but also the higher the voltage spike across the lifting magnet. High voltage spikes cause arcing between the contacts. In addition, fast rising voltage spikes also eventually wear out the lifting magnet insulation, and the insulation of the cables connecting the lifting magnet to the controller. To withstand these voltage spikes, generally in the magnitude of 750 V DC with systems using DC magnets rated at 240 V DC, the lifting magnet, cables, and the control system contacts and other components need to be constructed of more expensive materials, and also need to be made larger in size.

Lifting magnets are rated by their cold current (current through the magnet under rated voltage, typically 250V DC, when the magnet temperature is 25° C.). These lifting magnets are designed for a 75% duty cycle (in a 10 minute period the magnet can have voltage applied at 250V DC for 7 minutes 30 seconds and the remaining 2 minutes 30 seconds the magnet must be off for cooling or the magnet will overheat). Today, magnet control systems are limited by the rectified DC voltage supplying the magnet control (typically 250-350V DC). These systems control the voltage to the magnet and as the magnet heats up, the resistance rises and the current drops. As a magnet heats up, the magnet loses 25-35% in lifting capacity because the resistance of the wire increases and the current through the lifting magnet decreases.

SUMMARY

These and other problems are solved by a new and improved method and apparatus for controlling a lifting magnet using an AC source, described here.

In one embodiment, the voltage and the current are controlled during the charging of the lifting magnet during the lift cycle. Charging involves the phase that begins the "Lift" mode during which the current in the lifting magnet increases. Voltage levels up to 500V DC or more are applied to the lifting magnet during the charge. When a current value related to the cold current rating of the lifting magnet is reached, the current is limited to this value until the end of the "Lift" mode. The lifting magnet can overheat if the current is maintained at the cold current level or higher, so after a preset time, during which the material attaches to the lifting magnet, the voltage on the lifting magnet is reduced to a holding voltage which causes a relatively lower current than the current applied during the "Lift" of the lifting magnet. The period during which there is a holding voltage applied to the lifting magnet is the "Hold" mode and this "Hold" mode allows the lifting magnet to hold the material that the lifting magnet has already picked-up.

In one embodiment, the "Lift" mode is initiated by the operator. During the "Lift" mode, a first voltage is applied across the lifting magnet. Then, the operator can select a relatively higher voltage to continue to be applied to the magnet in order to secure a load that has been picked up by the magnet.

In one embodiment, the voltage levels during "Lift" and "Hold" modes are user-selectable.

In one embodiment, the ratio of "Lift" to "Hold" voltages is user-selectable, based on the type of application sought.

In one embodiment, the magnetic field is maintained in the lifting magnet from the magnet's cold state to the magnet's hot state during the charging of the lifting magnet. Since the lifting magnet's field is primarily controlled by NI (where N=turns of wire and I=current), maintaining the same current for a cold or hot magnet maintains substantially the same magnetic field.

In one embodiment, most of the lifting magnet energy used during the "Lift" and the "Drop" phases is returned to the line source rather than being dissipated in resistors, varistors, or other lossy elements.

In one embodiment, if during "Lift" or "Drop", the controller is accidentally disconnected from the line, such that the current cannot keep flowing in the lifting magnet, the voltage across the lifting magnet sharply rises and consequently this fast voltage rise turns one or more voltage protection devices before their breakover voltage is attained. In addition, the lifting magnet controller circuitry can be protected by the use of circuit breakers, such as, for example, a high speed breaker.

In one embodiment, switching of current for the lifting magnet is provided by solid-state devices.

In one embodiment, the control system is configured to increase the useful life of the lifting magnet by reducing voltage spikes in the lifting magnet circuit. During operation, the instantaneous voltage across the magnet typically should not exceed the line voltage, i.e., for a system rated 460 V AC RMS, peak voltage is $460\times\sqrt{2}=650$ V, whereas voltages in prior art systems typically exceed 750 V.

In one embodiment, the control system is configured to increase the useful life of the lifting magnet, by providing a "Hold" mode that reduces magnet heating.

In one embodiment, the control system is configured to save energy by providing a "Hold" mode that reduces energy consumption.

In one embodiment, the control system is configured to reduce the "Lift" time. A shorter "Lift" time helps to increase production by reducing the lifting magnet cycle times. Using a higher AC voltage can provide relatively shorter "Lift" times. Some existing systems use a step-down voltage transformer which reduces the maximum voltage that can be applied to the magnet during "Lift", and therefore these systems could not lift as quickly as systems with full line AC voltages.

In one embodiment, the control system is configured to reduce the "Drop" time. A shorter "Drop" time helps to increase production by reducing the lifting magnet cycle times. Some existing systems use a resistor, which causes voltage to decay with the current, leading to longer discharge times. Using a constant voltage source to discharge the lifting magnet energy allows a faster discharge.

In one embodiment, the control system is configured to monitor the lifting magnet resistance. Using the direct relationship between the magnet resistance and the magnet's winding temperature, resistance values corresponding to different meaningful temperature levels of the lifting magnet can be monitored.

In one embodiment, the control system is configured to indicate an alarm to the operator if the lifting magnet temperature rises above a threshold level.

In one embodiment, the control system is configured to protect and increase the useful life of the lifting magnet by providing a "Trip" mode, which, based on an indication of the lifting magnet's temperature, determines whether the system should directly enter "Drop" mode instead of "Lift" mode, to reduce magnet heating.

In one embodiment, the control system is configured to prevent the lifting magnet from sticking to the bottom and walls of magnetizable containers by providing a "Sweep" mode that reduces the voltage levels applied to the lifting magnet during the "Lift" and "Hold" modes.

In one embodiment, a user console allow the user to specify operating parameters and to view calculations of energy usage and energy saved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an overhead crane with lifting magnet.

FIG. **2**A shows an AC lifting magnet system.

FIG. **2**B shows an AC lifting magnet system with an optional DC Power Converter such as a DC Regulated Power Supply.

FIG. **3** illustrates an equivalent circuit for magnet resistance calculation.

FIG. **4**A shows voltage and current signals as the AC magnet controller is operated through "Lift", "Hold" and "Drop" modes for handling scrap material, for example.

FIG. **4**B shows voltage and current signals as the AC magnet controller is operated through "Lift", "Hold" and "Drop" modes for handling plates or slabs, for example.

FIG. **5** shows a general Sequential Function Chart (SFC).

FIG. **6** shows a flowchart for the Main SFC.

FIG. **7** shows a flowchart for the Ready SFC.

FIG. **8** shows a flowchart for the Lift SFC

FIG. **9** shows a flowchart for the Hold SFC.

FIG. **10** shows a flowchart for the Drop SFC.

FIG. **11** shows one embodiment of the DC Regulated Power Supply Voltage Selection.

FIG. **12** shows one embodiment of the DC Regulated Power Supply Current Selection.

FIG. **13** shows a communication setup page for user control of the lifting magnet system.

FIG. **14** shows a first parameter setup page for user control of the lifting magnet system.

FIG. **15** shows a second parameter setup page for user control of the lifting magnet system.

FIG. **16** shows a monitor page for user control of the lifting magnet system.

FIG. **17** shows an operations page for user control of the lifting magnet system.

FIG. **18** shows an energy computation page for user control of the lifting magnet system.

FIG. **19** shows a parameter diagram for user control of the lifting magnet system.

DETAILED DESCRIPTION

FIG. **1** shows an overhead crane with a bridge **190** provided to a trolley **191**. The trolley **191** is provided to a lifting magnet **113** controlled by a magnet controller **192**. The lifting magnet **113** is attached by cables to the magnet controller **192** which controls the lifting magnet **113**. The lifting magnet **113** is used to lift ferromagnetic materials such as, for example, one or more steel plates, steel girders, scrap steel, etc.

FIG. **2** shows a lifting magnet controller circuit **192** that includes a Logic Controller (LC) **100**. In one embodiment, the LC **100** can be a Programmable Logic Controller (PLC). The LC **100** receives input commands from an operator console **260** and provides alarm and trip relay outputs. The operator console **260** can be configured as a computer with a display and human interface devices (e.g., mouse, keyboard, touchscreen, etc.). Outputs from the logic controller **100** are provided to respective switches **101-112**. The switches **101-103** and **110-112** are configured in a positive bridge **250** to provide current to the lifting magnet **113** in a first direction, and switches **104-109** are configured in a negative bridge **251** to provide current to the lifting magnet **113** in a second direction. The switches **101-112** can be any type of mechanical or solid-state switch device so long as the devices are capable of switching at a desired speed and can withstand voltage spikes. For convenience, and not by way of limitation, FIG. **2** shows the switches **101-112** as thyristors, each having an anode, a cathode and a gate. One of ordinary skill in the art will recognize that the switches **101-112** can be bipolar transistors, insulated gate bipolar transistors, field-effect transistors, MOSFETs, etc. One of ordinary skill in the art will also recognize that the number of switches used can be less or more than the twelve shown; using a greater number of switches reduces ripple.

FIG. **2**A shows the lifting magnet controller. FIG. **2**B shows one embodiment of the lifting magnet controller where a DC Power Converter such as a DC Regulated Power Supply **400** is used. The DC Regulated Power Supply **400** is one embodiment of a DC Power Converter, and is used as an example and not by way of limitation.

In FIGS. **2**A and **2**B, the thyristors **101-112** will initially conduct when the anode is positive with respect to the cathode and a positive gate current or gate pulse is present. The gate current can be removed once the thyristor has switched on. The thyristors **101-112** will continue to conduct as long as the respective anode remains sufficiently positive with respect to the respective cathode to allow sufficient holding current to flow. The thyristors **101-112** will switch off when the respective anode is no longer positive with respect to the respective cathode. The amount of rectified DC voltage can be controlled by timing the input to the respective gate. Applying current on the gate without delay to the natural commutation time will result in a higher average voltage applied to the lifting magnet **113** (where natural commutation time is understood in the art to be the time at which the SCRs would start conducting if they were replaced by diodes). Applying current on the gate later will result in a lower average voltage applied to the lifting magnet **113**. When the current in the magnet needs to be turned off, the application of the current on the gate can be further delayed to the point where voltage across the magnet **113** reverses, restoring the magnet energy to the AC supply. The period of time which precedes the "Drop" mode is called discharge. Six thyristors, **101-103** and **110-112**, are connected together to make a three-phase bridge rectifier **250**. The gating angle of the thyristors in relationship to the AC supply voltage determines how much rectified voltage is available. Converted DC voltage (V_{DC}) is equal to 1.35 times the RMS value of input voltage (V_{RMS}) times the cosine of the phase angle (cos α): $V_{DC}=1.35\times V_{RMS}\times\cos\alpha$. The value of the DC voltage that can be obtained from a 460 V AC input is thus −621V DC to +621V DC. The addition of the second, negative bridge **251** (i.e., connected in reverse with respect to the first positive bridge **250**) in the circuit allows for four-quadrant operation. The positive bridge **250** charges the lifting magnet **113** during the "Lift" mode and returns energy from the lifting magnet **113** back to the AC input during discharge. This four-quadrant circuit can also be used to demagnetize the lifting magnet **113** by applying voltage in the opposite polarity by using the negative bridge **251** as the bridge used to bring voltage to the lifting magnet **113** and returning energy to the AC input (for example, at the end of "Drop"). The time during which the negative bridge **251** restores energy from the magnet back to the AC input is called the secondary discharge. Those skilled in the art will recognize that the polarity of the lifting magnet **113** is reversible, such that the positive bridge **250** can be used to demagnetize the lifting magnet **113** during the "Drop" mode and the negative bridge **251** can be used to magnetize the lifting magnet **113** during the "Lift" mode; the previous directions have been described for convenience. It will also be apparent to one skilled in the art that the use of three-phase power is not necessary for all cycles.

The thyristors **101-112** act as transient protection devices themselves, and prevent failures in the DC Regulated Power Supply **400** or in the AC input power from damaging components in the DC Regulated Power Supply **400** by conducting before the output voltage of the supply rises above the breakover voltage of the thyristors by freewheeling the magnet coil. The thyristors **101-112** are usually chosen so that their breakover voltage is higher than the greatest voltage expected to be experienced from the power source, so that they can be turned on by intentional voltage pulses applied to the gates. If other types of switches are used, those skilled in the art will recognize that transient protection devices can be added to protect against voltage spikes.

FIG. **3** shows the actual and equivalent circuits used for magnet resistance calculation. Overheating of the lifting magnet **113** can lead to melting or short-circuits, and a need to rewind the lifting magnet **113**. The internal temperature of the lifting magnet **113** can be measured by a thermistor or other temperature sensor, if such a device was embedded in the lifting magnet **113** during the process of magnet winding. In one embodiment, the temperature of the lifting magnet **113** is calculated by measuring the electrical resistance **301** of the magnet **113** because the resistance **301** of the lifting magnet **113** is substantially proportional to the temperature of the lifting magnet **113**. The magnet resistance **301** is calculated based on readings of voltage and current across the lifting magnet **113** or across the load side of the DC Regulated Power Supply **400** and by taking into account the resistance **302** of the cables. The resistance **302** of the cables can either be (1) calibrated out, (2) measured and subsequently subtracted from the total resistance reading, or (3) disregarded if the resistance **302** is assumed to be small in relation to the magnet resistance **301**. The cables are not expected to get hot because of the low value of their resistance **302** and their exposure to air. However, the lifting magnet **113** gets hot because of the relatively high density of windings in relation to the surface area available for cooling (typically, cooling is achieved by natural convection). Lifting magnets are generally designed for a resistance increase of about 50% when they get hot. The formula to calculate the magnet resistance **301** at a given temperature is: $R_H=R_0\,(1+K\,\Delta\theta)$, where R_0=cold resistance of the lifting magnet **113**, in Ω, K=temperature coefficient of the magnet **113** (typically 0.004 Ω/° C. for a copper- or aluminum-wound magnet), and Δθ=change in temperature, in ° C.

The lifting magnet's calculated resistance **301** is compared to two parameters: the "Alarm resistance" and the "Trip resistance". The "Alarm resistance" is a threshold value which, if exceeded, triggers the system to provide an alarm to warn the operator to either turn off the lifting magnet **113** or to indicate that the system is picking up materials which are too hot, or that the cable is partially cut, or that a connection is loose. The "Trip resistance" is a threshold value which, if exceeded, triggers the system to protect the lifting magnet **113** from overheating. When the trip resistance is exceeded, the system activates a trip relay. If the trip relay is activated when the system is in "Hold" mode, the system will continue through the normal modes of operation of "Hold" and "Drop". However, if the Trip relay is activate when the operator requests a "Lift", the system will not enter into "Lift" mode and instead go directly to "Hold" mode.

FIG. **4**A shows voltage and current during the "Lift", "Hold" and "Drop" modes for applications such as scrap material handling. The "Lift" mode is initiated by the operator. During the "Lift" mode, the positive bridge **250** applies a relatively high voltage level across the lifting magnet **113** until the current reaches the limiting current for the lifting magnet **113** through the positive bridge **250**. The "Lift" mode lasts long enough to charge the lifting magnet **113** yet is short enough to prevent overheating of the lifting magnet **113**. The length of time for the "Lift" mode will vary based on the time constant of the lifting magnet **113**, the desired current for the lifting magnet **113** and the voltage applied to the lifting magnet **113**. During the charge, the first portion of the "Lift" mode, there is a relatively high average voltage applied to the lifting magnet **113** (typically adjusted around 500V for an AC supply of 460V AC) and the current rises relatively fast. Once the current has risen, then the current is limited and held at a plateau for a specified time to allow magnetic field to build up.

The "Hold" mode is initiated automatically after a specified time in "Lift" mode. During the "Hold" mode, the positive bridge **250** applies a different (lower) voltage level across the lifting magnet **113**, for as long as the operator needs in order to move the load. The "Hold" voltage is set below the lifting magnet **113** rated voltage, and the lifting magnet **113** is thus expected to cool down somewhat during the "Hold" mode. In other words, for safety reasons, an energized lifting magnet **113**, possibly carrying an overhead load, is not made to automatically shut down. Because of the reduced voltage level, in "Hold" mode, the current decreases to a second lower plateau. Under normal conditions, in the "Hold" mode, the load has already been attracted, air gaps are at a relatively low level, and therefore, less magnetic flux is required to keep the load attached. Therefore, the current and the magnetic field across the lifting magnet **113** can be reduced. At the end of the "Hold" mode, the firing angle of the thyristors phases back and energy from the lifting magnet **113** is returned to the AC input until current reaches zero.

The "Drop" mode is initiated by the operator and causes the "Lift" or "Hold" mode to terminate. During the "Drop" mode, the positive bridge **250** thyristors' firing pulses get delayed to cause the polarity of voltage across the lifting magnet **113** to reverse. After the current from the "Drop" mode or the "Hold" mode reaches zero, the negative bridge **251** applies a voltage of reverse polarity across the lifting magnet **113**, i.e. reverses the sense of voltage signal until the current reaches the current limit for the lifting magnet **113** through the negative bridge **251**. The "Drop" mode expires after yet another specified time. During the "Drop" mode, the current value is specified such as to produce a magnetic field in the lifting magnet **113** that is of the same magnitude but in an opposite direction of the residual magnetic field across the lifting magnet **113**, such that the two fields cancel each other. When the lifting magnet **113** is free of residual magnetic field, the load detaches freely from the lifting magnet **113**.

In FIG. **4**A, during phase **0**, the lifting magnet **113** is idle. Phase **1** represents the "Lift" mode during voltage regulation, where the voltage can be adjusted to a relatively high value in order to magnetize the lifting magnet **113** relatively quickly. Phase **2** represents the "Lift" mode during current limiting, where the current limit can be adjusted close to the cold current rating for the lifting magnet **113**. Phase **3** represents the "Hold" mode, during which the current is adjusted to be a portion of the cold current such that the lifting magnet **113** does not warm up, while still holding the load; the magnitude of the current during the "Hold" mode can be adjusted such as to compensate for the amount of magnetic hysteresis. Phase **4** represents the "Drop" mode during transient, where the current is adjusted to compensate for the magnetic hysteresis. Phase **5** represents the "Drop" mode, where both current and voltage are held constant, in order to match the magnetic time constant of the lifting magnet **113**.

FIG. **4**B shows voltage and current during the "Lift", "Hold" and "Drop" modes for applications such as handling of slab or plates material. The "Lift" mode is initiated by the operator. During the "Lift" mode, the positive bridge **250** applies a preset voltage level across the lifting magnet **113**. The length of time for the "Lift" mode will vary based on the time constant of the lifting magnet **113**. During the charge, the slab or plates attach to the lifting magnet **113**. After the charge, the operator starts to hoist the lifting magnet **113** for a few feet. If the operator wishes to hoist the load further, then the operator can apply a relatively higher voltage to the lifting magnet **113** during the "Hold" mode in order to maintain the load attached to the lifting magnet **113**. The "Drop" mode operates the same for this slab or plates' material application as it does for the scrap materials handling application.

In FIG. **4**B, during phase **0**, the lifting magnet **113** is idle. Phase **1** represents the "Lift" mode where a preset voltage is applied to the lifting magnet **113**. Phase **2** represents the "Hold" mode, during which the operator selects a relatively higher voltage to apply across the lifting magnet **113**. Phase **4** represents the "Drop" mode during transient, where the current is adjusted to compensate for the magnetic hysteresis. Phase **5** represents the "Drop" mode, where both current and voltage are held relatively constant, in order to match the magnetic time constant of the lifting magnet **113**.

In addition to the above three modes, there is a "Sweep" mode, which is optionally activated by the operator. The "Sweep" mode is for applications where the rail car or container to be unloaded has its bottom or walls formed of magnetic material. When unloading is almost complete, to prevent the lifting magnet **113** from sticking to the bottom or walls of the rail car or container, a "Sweep" switch can be activated by the operator to reduce the "Lift" and "Hold" voltages. The reduced voltage across the lifting magnet **113** prevents the magnetized load from attaching to the bottom or walls of the rail car or container while the lifting magnet **113** is unloading.

In one embodiment, the "Lift", "Hold", "Drop" and "Sweep" modes of the magnet controller circuit described above, used to control the lifting magnet **113**, can be controlled through the use of the Logic Controller (LC) **100**.

The logical programming of the LC **100** is represented in sequential function charts (SFC). SFC is a graphical programming language used for logical controllers, defined in IEC 848. SFC can be used to program processes that can be split into steps.

FIG. **5** shows a general SFC. Main components of SFC are: steps with associated actions, transitions with an associated logic condition or associated logic conditions, and directed links between steps and transitions. Steps can be active or inactive. Actions are executed for active steps. A step can be active for one of two motives: (1) the step is an initial step as specified by the programmer, (2) the step was activated during a scan cycle and was not deactivated since. A step is activated when the steps above that step are active and the connecting transition's associated condition is true. When a transition is passed, the steps above the transition are deactivated at once and the steps below the transition are activated at once.

An SFC program has three parts: (1) preprocessing, which includes power returns, faults, changes of operating mode, pre-positioning of SFC steps, input logic; (2) sequential processing, which includes steps, actions associated with steps, transitions and transition conditions; and (3) post-processing, which includes commands from the sequential processing for controlling the outputs and safety interlocks specific to the outputs.

FIG. **6** shows a flowchart for the Main SFC. In FIG. **6**, step "**10** Main" has no associated actions and the transition to step "**20** Ready" is true. Step "**10** Main" can be accessed either if a "Drop" input is received by the operator while in step "**20** Ready" or when the SFC is initialized. Step "**20** Ready" is initiated either automatically after step "**10** Main" or after a preset time TM**2** in step "**50** Drop". Step "**20** Ready" starts the Ready SFC. From step "**20** Ready", a "Drop" command by the operator calls step **10**. Step "**30** Lift" starts the Lift SFC. "Lift" is initiated by a lift command from steps "**20** Ready" or "**50** Drop". Step "**40** Hold" is initiated either automatically after a preset time TM**1** in step "**30** Lift", or immediately after a "Lift" input in step "**20** Ready" if the magnet temperature trip relay is active. Step "**40** Hold" initiates the Hold SFC. Step "**50** Drop" is initiated by a "Drop" rising edge from either step "**30** Lift" or "**40** Hold", and step "**50** Drop" initiates the Drop SFC.

FIG. **7** shows a flow chart for the Ready SFC. Step "**21** Ready" is the initialization step. Step "**21** Ready" will be active when the Main SFC is not in step "**20** Ready". Step "**21** Ready" is not associated with any actions. Step "**20** Ready" getting active in the Main SFC causes transition X**20** to be true and to make step "**22** Run Off" active. Once step "**20** Ready" is active, unless step "**20** Ready" stops to be active and causes $\overline{X20}$ to be true and the SFC to return to step "**21** Ready", the SFC stays in step "**22** Run Off". While the SFC is in step "**22** Run Off", the LC **100** sends commands to the control circuitry to turn off the current in the magnet **113**. From step "**22** Run Off", the SFC transitions to step "**23** Voltage Selection **1** Off" when the Send Command Done is true, and the SFC transitions from step "**23** Voltage Selection **1** Off" to step "**24** Negative Bridge Off" when the Send Command Done is true. From step "**24** Negative Bridge Off", the SFC transitions to step "**27** Done" when the Send Command Done is true.

FIG. **8** shows a flowchart for the Lift SFC. The first step to be activated, "**32** Run On", is to reduce to a minimum the delay time between the activation of the "Lift" input by the operator and the response by the circuitry. Steps "**35** Negative Bridge Off" and "**36** Voltage Selection **1** Off" are used if the step before "**30** Lift" was "**50** Drop" in the Main SFC and the Send Command Done is true. "Sweep" is a switch that can be toggled by the operator. If "Sweep" is on, "Voltage Selection **2**" and "Current Limit Selection **2**" are on, and the system selects the second set of voltage references and the second current limit. If "Sweep" is off, "Voltage Selection **2**" and "Current Limit Selection **2**" are off, and the system selects the primary set of voltage references and the primary current limit.

FIG. **9** shows a flow chart for the Hold SFC. Step "**41** Hold" is the initialization step. Step "**40** Hold" getting active in the Main SFC causes transition X**40** to be true and to make step "**42** Voltage Selection **1** On" active. Once the step "**42** Voltage Selection **1**On" is active, unless step "**40** Hold" stops to be active and causes $\overline{X40}$ to be true and the SFC to return to step "**41** Hold", the SFC stays in step "**42** Voltage Selection **1** On". While the SFC is in step "**42** Voltage Selection **1** On", the LC **100** sends commands to control the lifting magnet circuitry.

The SFC transitions from step "**42** Voltage Selection **1** On" to step "**49** Run On" when Send Command Done is true. The SFC transitions from step "**49** Run On" to step "**90** Negative Bridge Off" when Send Command Done is true. The SFC transitions from step "**90** Negative Bridge Off" to step "**43** Ready" when Send Command Done is true. Once the SFC is in step "**43** Ready", after the timer TM**3** elapses, the voltage and current across the lifting magnet **113** are stabilized and the LC **100** gets updates from the system for readings of Volts across the lifting magnet **113** and Amps going across the lifting magnet **113**. Based on those readings, the LC **100** calculates the magnet resistance and determines whether or not the alarm resistance is exceeded, and whether or not the trip resistance is exceeded. Each of these updates is requested after the previous update is done.

FIG. **10** shows a flow chart for the Drop SFC. Step "**50** Drop" getting active in the Main SFC causes transition X**50** to be true and to make step "**52** Negative Bridge On" active. In step "**52** Negative Bridge On", the system selects the negative bridge **251**. The current limit for the negative bridge **251** is set at a fraction of the current limit for the positive bridge **250**. Then, in step "**55** Voltage Selection **1** Off", voltage selection is reset. The system remains in "Drop" mode until the Main SFC exits step "**50** Drop" either after timer TM**2** expires or when a "Lift" command is requested by the operator.

In one embodiment, the circuitry used to control the lifting magnet **113** can be obtained by appropriately programming a DC Regulated Power Supply **400**, normally used to control motors. The LC **100** can be set up with access to the DC Regulated Power Supply **400** logic, allowing the setting of parameters to be changed to suit different operating conditions.

In one embodiment, the the Mentor II DC Drive manufactured by Control Techniques of Minnesota, United States can be used as the DC Regulated Power Supply.

The thyristors in the DC Regulated Power Supply **400** are fired when the "Run ON" command is sent during step "**32** Run On" of the Lift SFC.

During the "Lift" mode, the positive bridge **250** applies the voltage from the DC Regulated Power Supply **400**, usually set around 500V DC across a 240V DC rated lifting magnet **113** to boost the charge until the current gets limited by the limiting current for the lifting magnet **113**. In addition, the "Lift" time is controlled by the value in timer TM**1** of the LC **100**.

During the "Hold" mode, the positive bridge **250** applies a voltage of around 180 V DC across a 240 V DC rated magnet **113**. This holding voltage is adjustable and set in the LC **100**. In addition, after being in "Hold" mode for about 5 seconds, as preset in timer TM**3** of the LC **100**, and periodically at each period of time preset in timer TM**3**, the LC **100** reads the current and voltage across the DC Regulated Power Supply **400**.

During the "Drop" mode, the negative bridge **251** is turned on by changing the value in parameter "Bridge Selector", shown in FIG. **11**. During the "Drop" mode, the current can be limited by the parameter "Current Limit for Negative Bridge" shown in FIG. **12**. In addition, the time for the "Drop" mode is preset by parameter TM**2**.

During the "Sweep" mode, depending on whether a "Sweep" command is received by the operator at the LC **100**, "Voltage Selection **2**" is set to on or off in the DC Regulated Power Supply **400**. If "Sweep" is off, "Voltage Selection **2**" is off, as shown in FIG. **11**. Therefore, the reference voltages in "Voltage Reference **1**" and "Voltage Reference **2**" of the DC Regulated Power Supply **400** are respectively selected during "Lift" and "Drop", depending on the value of "Voltage Selection **1**". On the other hand, if "Sweep" is on, "Voltage Selection 2" is enabled. By enabling "Voltage Selection 2", the "Voltage Reference 3" and "Voltage Reference 4" of the DC Regulated Power Supply **400** are respectively selected during "Lift" and "Drop", again, depending on the value of "Voltage Selection 1". Furthermore, during the "Sweep" mode, the current is limited by parameter "Current Limit 2", as shown in FIG. **12**.

It will be apparent to those skilled in the art how the "Lift" and "Hold" modes described above function when the system is used in a slab or plates material handling application, and the voltage levels are adjusted accordingly.

The temperature protection for the lifting magnet **113** is controlled through the use of parameters "Alarm Resistance" and "Trip Resistance". The resistance value at which the system activates an alarm relay during the "Hold" mode is set into parameter "Alarm Resistance", based on the lifting magnet **113** manufacturer's rated hot current. The resistance value at which the system activates a trip relay is set into parameter "Trip Resistance", based on the insulation class temperature of the lifting magnet **113**. When the resistance **301** of the lifting magnet **113** exceeds the value set in parameter "Trip Resistance", the next cycle begins directly in "Hold" mode. When the lifting magnet **113** cools down and its resistance value **301** becomes less than the value set in parameter "Trip Resistance", then the system enters "Lift" mode again. Cable ohmic resistance **302** of the wiring between the lifting magnet **113** and the LC **100** is set in parameter "Wiring Resistance". To calculate the magnet resistance, the LC **100** divides the voltage by the current and then subtracts the value set in "Wiring resistance".

In addition to the above parameter settings, some parameters in selected DC Regulated Power Supplies can be adjusted to accommodate for highly inductive loads like the lifting magnet **113**. Generally, voltage loop and current loop PID gain circuitries need to be optimized, current feedback resistors scaled to accommodate for the inductance of the magnet **113**, and a safety margin of 1 supply cycle added to the bridge changeover logic to prevent shorting the line by having a thyristor in one bridge firing while another thyristor in the other bridge were still conducting.

FIG. **13** shows a communication setup page **1300** for display on the operator console **260** for user control of the lifting magnet system. The communication setup page **1300** includes a communication selection control to allow the user to select the communication system (e.g., Ethernet, serial bus, etc.) used for communication between the operator console **260** and the control system **100**. Depending on the type of communication system chosen, the user can also specify various communication parameters such as, for example, port number, bit rate, drive address, polling interval, IP address, transmission timeout, etc. FIG. **14** shows a first parameter setup page **1400** for display on the operator console **260** for user control of the lifting magnet system. The page **1400** includes dialog controls to allow the user to specify the operating parameters listed in Table 1.

TABLE 1

Parameter ID	Description	Units
15.18	Cold Current	Amps
15.06	Normal mode: Lift Voltage (e.g., the voltage during phase 1 described in connection with in FIG. 4A)	Volts
15.07	Normal mode: Lift Current Limit (e.g., the current during phase 2 described in connection with in FIG. 4A)	Amps

TABLE 1-continued

Parameter ID	Description	Units
15.08	Normal mode: Economy Voltage (e.g., the voltage during phase 3 described in connection with in FIG. 4A)	Volts
15.09	Normal mode: Drop Voltage (e.g., the voltage during phase 4 described in connection with in FIG. 4A)	Volts
15.10	Normal mode: Drop Current Limit (e.g., the current during phase 5 described in connection with in FIG. 4A)	Amps
15.11	Normal mode: Lift "Pick" Time (e.g., the time corresponding to the combination of phase 1 and phase 2 in FIG. 4A)	Seconds
15.12	Normal mode: Drop "Clean" Time (e.g., the time corresponding to the combination of phase 4 and phase 5 in described in connection with in FIG. 4A)	Seconds
16.06	Sweep mode: Lift Voltage (e.g., the voltage during phase 1 described in connection with in FIG. 4B)	Volts
16.07	Sweep mode: Lift Current Limit (e.g., the current during phase 2 described in connection with in FIG. 4B)	Amps
16.08	Sweep mode: Economy Voltage (e.g., the voltage during phase 3 described in connection with in FIG. 4B)	Volts
16.09	Sweep mode: Drop Voltage (e.g., the voltage during phase 4 described in connection with in FIG. 4B)	Volts
16.10	Sweep mode: Drop Current Limit (e.g., the current during phase 5 described in connection with in FIG. 4B)	Amps
16.11	Sweep mode: Lift "Pick" Time (e.g., the combined time of phase 1 and phase 2 described in connection with in FIG. 4A)	Seconds
16.12	Sweep mode: Drop "Clean" Time (e.g., the combined time of phase 4 and phase 5 in FIG. 4B.)	Seconds
07.08	Resistance alarm set point	Ohms
07.09	Resistance Trip set point	Ohms
07.10	Cable Resistance (e.g., the resistance 302 shown in FIG. 3.)	Ohms

FIG. **15** shows a second parameter setup page **1500** for display on the operator console **260** for user control of the lifting magnet system. The parameter page **1500** allows the user to specify parameters corresponding to dribble/plate options wherein multiple objects (e.g., steel plates) are dropped in sequence. The page **1500** includes a dialog control to allow the user to specify a Parameter 15.14 that specified a dribble mode. Other dialog controls allow the user to specify Parameters 15.08, 15.29, 15.16-15.20, 16.01, and 16.16-16.21. The dribble modes can include one or more of the following 6 modes:

1. Dribble Disabled.
2. Press and Release of the Dribble button causes the magnet voltage to ramp down to zero at a rate specified by the Parameter 15.16 (volts/second). Pressing the DROP button overrides and inverts this function.
3. Press and hold of the Dribble button begins the ramp to zero. Releasing the Dribble button stops the ramp and holds at the present voltage level. Press and hold the Dribble button again causes the voltage to continue to ramp down from current voltage level. Pressing the DROP button overrides and inverts this function.
4. Press and release of the Dribble button begins a ramp to zero. The next press and release of the Dribble button stops the ramp and holds at current voltage level. The next press and release of the Dribble button continues the ramp from he current voltage level. Future presses and releases cycle the ramp on and off. Pressing the DROP button overrides and inverts this function.
5. Press and hold of the PLATE button begins a ramp to zero. Release of the PLATE button stops the ramp, saves

the current voltage value, and increases hold voltage by a preset value specified by the Parameter 15.19 (e.g., 0V to 100V). The increased hold voltage does not exceed original voltage setting. Press and hold the PLATE button again to continue the ramp from the saved voltage level. Pressing the DROP button overrides and inverts this function.

6. Press and Release of the PLATE button begins a ramp to zero. A subsequent press and release of the PLATE button stops the ramp, saves the current voltage value, and increases the hold voltage by a preset value specified by the Parameter 15.19. Increased hold voltage does not exceed the original voltage setting. Future presses of the PLATE button cycle the ramp on and off from the saved voltage levels. Pressing the DROP button overrides and inverts this function.
7. Press and Release of the Plate button drops the voltage to a first preset voltage level specified by a Parameter 16.16. After a time delay specified by a Parameter 15.20 (e.g., 0 to 25.5 seconds) the voltage is raised by a preset value specified by the Parameter 15.19. The increased hold voltage does not exceed the original voltage setting. Second press and release drops voltage to second preset voltage level specified by a Parameter 16.17. The time delay is again applied and then the voltage is raised to the increased hold voltage. Further presses of the PLATE button drop the voltage to third, forth, and fifth preset voltage levels specified by Parameters 16.18, 16.19, and 16.20, respectively. Pressing the DROP button overrides and inverts this function.

In one embodiment, the dribble/plate modes 4, 5, and/or 6 are stopped and the system returns to full hold voltage when the bridge/trolley Parameter 16.21 is set true (e.g., a user dialog checkbox corresponding to the Parameter 16.21 is checked) and the bridge **190** or trolley **191** moves.

Although the dribble/plate modes are normally used during drop, in one embodiment, the dribble/plate modes can be used in lift to allow an operator to pick up a desired number of plates or objects.

Using a checkbox corresponding to Parameter 15.29, the user can instruct the system to use an adjusted lift voltage where the lift voltage is set using a potentiometer or other user control corresponding to Parameter 15.08. The economy hold voltage (e.g., the voltage used during phase **3** of FIGS. **4**A and **4**B is specified by the Parameter 15.08.

FIG. **16** shows a monitor page **1600** for display on the operator console **260** for user control of the lifting magnet system. The monitor page **1600** displays various status and diagnostic values parameters such as, output voltage to the magnet (Parameter 03.04), output current to the magnet (Parameter 05.02), input voltage (Parameter 07.06), magnet resistance (Parameter 03.14). The monitor page also indicates the off/on status of various modes and settings, such as: run mode, lift mode, drop mode, sweep mode, bridge/trolley override, dribble/plate mode, enable. The monitor page includes a trip indicator and display showing a trip code **1610**.

In one embodiment, the trip codes **1610** include one or more of the following conditions: Hardware Fault, Phase Sequence error, External Trip, External Power Supply error, Current (Control) Loop Open Circuit, Serial Communications Link (Interface) Loss, Field Overcurrent, Magnet Overheat, Field On, Feedback Reversal, Field Loss, Feedback Loss, Power Supply Loss, Overcurrent. Current * Time Trip (e.g., current * time has exceeded the defined threshold), Thermistor Overheat (Thermal Switch), EEprom Failure, Software Error, RS485 Trip, and/or Communication Error.

FIG. **17** shows an operations page **1700** for display on the operator console **260** for user control of the lifting magnet system. The operations page **1700** includes dialog displays to show the following: total number of operations, total time of magnet operation, total power-up time. For normal mode, the operations page **1700** includes dialog displays to show: number of operations, lift time, economy time (e.g., phase **3** time), and drop time. For sweep mode, the operations page **1700** includes dialog displays to show: number of operations, lift time, economy time (e.g., phase **3** time), and drop time. The operations page **1700** includes dialog buttons to allow the user to reset the operations counters, operation times, and power-up timer.

FIG. **18** shows an energy computation page **1800** for display on the operator console **260** for user control of the lifting magnet system **100**. The energy page **1800** includes dialog displays to allow the user to compare energy usage of the magnet controller **100** with energy usage of a prior system and thereby allow the user to assess the energy cost savings of the magnet controller **100**. The energy page **1800** includes dialog controls to allow the user to specify the parameters of the prior system. These prior system parameters include: normal mode lift voltage, normal mode hold voltage, normal mode drop voltage, normal mode lift time, normal mode drop time, normal mode dropping resistor value, sweep mode lift voltage, sweep mode hold voltage, sweep mode economy time, sweep mode lift time, and sweep mode drop time. The energy computation page **1800** also includes a dialog control **1801** to allow the user to specify the cost of energy.

The energy computation page **1800** includes dialog displays to show energy computations, including: energy usage by the controller **100**, calculated energy usage if the prior system had been used instead of the controller **100**, energy savings of the controller **100** in kWHr, energy savings of the controller **100** in dollars.

FIG. **19** shows a parameter diagram **1900** for display on the operator console **260** for user control of the lifting magnet system. In one embodiment, the parameter diagram **1900** corresponds to the voltage and current diagram in FIG. **4**A with corresponding labels for the normal mode parameters 15.06-15.12 discussed in connection with the setup page **1400** of FIG. **14**. In one embodiment, the parameter diagram **1900** corresponds to the voltage and current diagram in FIG. **4**B with corresponding labels for the sweep mode parameters 16.06-16.12 discussed in connection with the setup page **1400** of FIG. **14**. In one embodiment, the user can select between diagrams corresponding to normal mode and sweep mode.

In one embodiment, the user console provides three levels of security. In one embodiment, the different levels are password protected. In one embodiment, the levels are protected using different passwords. A first security level (Level 0) provides only read-only access. A second security level (Level 1) provides read/write access to the various parameters except for the parameters on the energy page **1800**. A third security level (Level 2) provides read/write access to all parameters.

It will be evident to those skilled in the art that the invention is not limited to the details of the foregoing illustrated embodiments and that the present invention may be embodied in other specific forms without departing from the spirit or essential attributed thereof; furthermore, various omissions, substitutions and changes may be made without departing from the spirit of the inventions. The foregoing description of the embodiments is, therefore, to be considered in all respects as illustrative and not restrictive, with the scope of the invention being delineated by the appended claims and their equivalents.

What is claimed is:

1. A lifting magnet system, comprising:

a three-phase AC power source;

a positive bridge circuit comprising six thyristors, wherein a first pair of thyristors are arranged in series with a first phase of said three-phase AC power source, a second pair of thyristors are arranged in series with a second phase of said three-phase AC power source, and a third pair of thyristors are arranged in series with a third phase of said three-phase AC power source wherein during lift, said positive bridge circuit is configured to generate a first voltage, and during hold, said positive bridge circuit is configured to generate a second voltage less than said first voltage, in a sweep mode, said positive bridge circuit is configured to generate a third voltage during sweep lift that is less than said first voltage and a fourth voltage during sweep hold that is less than said second voltage;

a negative bridge circuit comprising six thyristors, wherein a fourth pair of thyristors are arranged in series with said first phase of said three-phase AC power source, a fifth pair of thyristors are arranged in series with said second phase of said three-phase AC power source, and a sixth pair of thyristors are arranged in series with a third phase of said three-phase AC power source,

wherein said first pair of thyristors of said positive bridge circuit are arranged in parallel with said fourth pair of thyristors of said negative bridge circuit, said second pair of thyristors of said positive bridge circuit are arranged in parallel with said fifth pair of thyristors of said negative bridge circuit, and said third pair of thyristors of said positive bridge circuit are arranged in parallel with said sixth pair of thyristors of said negative bridge circuit;

an electromagnet;

a logic controller controlling said positive bridge circuit and said negative bridge circuit, during lift said logic controller controlling the thyristors in the positive bridge circuit in repeating sequence to output substantially direct current to the electromagnet and to apply said first voltage to the electromagnet to charge the electromagnet rapidly, during hold said logic controller controlling the thyristors in the positive bridge circuit in repeating sequence to output substantially direct current to the electromagnet and to apply said second voltage to the electromagnet that is less than the first voltage applied during lift in order to prevent damage to the electromagnet,

during sweep lift said logic controller controlling said thyristors in said positive bridge circuit in repeating sequence to apply said third voltage to said electromagnet that is less than said first voltage,

during sweep hold said logic controller further controlling said thyristors to apply a fourth voltage to said electromagnet that is less than said second voltage,

during drop said logic controller controlling the thyristors in the negative bridge circuit in repeating sequence to output substantially direct current to the electromagnet and to apply a voltage to the electromagnet that is the reverse of the voltage applied during lift to demagnetize the electromagnet; and

a user console to allow a user to specify said sweep mode applied during lift.

2. The lifting magnet system of claim **1**, wherein said thyristors prevent damage to themselves by automatically conducting before the voltage across the electromagnet rises above the breakover voltage of said thyristors.

3. The lifting magnet system of claim **1**, wherein the breakover voltage of said thyristors is higher than the greatest voltage expected to be experienced from the power source.

4. The lifting magnet system of claim **1**, wherein said console allows said user to select a dribble/plate mode.

5. The lifting magnet system of claim **1**, wherein said console allows said user to select a dribble ramp rate.

6. The lifting magnet system of claim **1**, wherein said console displays energy saved by the lifting magnet system.

7. The lifting magnet system of claim **1**, wherein a user can specify stepped voltages for use in a dribble mode.

8. A control system for lifting magnet, comprising:

a first bridge comprising a plurality of switches wherein said plurality of switches in said first bridge comprise at least a first serial pair of switches configured to transmit current in a first direction wherein during lift, said first bridge is configured to generate a first voltage, and during hold, said first bridge is configured to generate a second voltage less than said first voltage, in a sweep mode, said first bridge circuit is configured to generate a third voltage during sweep lift that is less than said first voltage and a fourth voltage during sweep hold that is less than said second voltage;

a second bridge comprising a plurality of switches wherein said plurality of switches in said second bridge comprise at least a second serial pair of switches configured to transmit current in a second direction, wherein the first and second serial pairs of switches are further arranged in parallel; and

a logic controller controlling said first bridge and said second bridge, during lift said logic controller controlling the switches in the first bridge in repeating sequence to output substantially direct current to the lifting magnet and to apply the first voltage to the lifting magnet to charge the lifting magnet,

during hold said logic controller controlling the switches in the first bridge in repeating sequence to output substantially direct current to the lifting magnet and to apply the second voltage to the lifting magnet lower than the first voltage applied during lift to prevent damage to the lifting magnet,

during sweep lift, said logic controller controlling said switches in said first bridge in repeating sequence to apply said third voltage to said lifting magnet that is less than said first voltage,

during sweep hold, said logic controller further controlling said switch to apply a fourth voltage to said lifting magnet that is less than said second voltage,

during drop said logic controller controlling the switches in the second bridge in repeating sequence to output substantially direct current to the lifting magnet and to apply a voltage to the lifting magnet that is the reverse of the first voltage applied during lift to demagnetize the lifting magnet wherein a user specifies one or more operating parameters for a normal mode, one or more operating parameters for the sweep mode, and where the user can select from a plurality of dribble/plate modes.

9. The control system of claim **8**, wherein said switches comprise thyristors.

10. The control system of claim **8**, wherein said switches are turned on before the voltage across the lifting magnet rises above the drain-source voltage of said switches.

11. The control system of claim **8** where the voltage applied during lift is different than the voltage applied during hold.

12. The control system of claim **8** where the voltage applied during lift is greater than the voltage applied during hold.

13. The control system of claim **8** where the voltage applied during lift is less than the voltage applied during hold.

14. The control system of claim **8** where the voltage applied during lift is at least twice the voltage applied during hold.

15. The control system of claim **8** where the voltage applied during lift and the voltage applied during hold are user-selectable.

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